Framework for Owner's Project Requirements for Total Structural Systems (OPRTSS)

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Framework for Owner's Project Requirements for Total Structural Systems (OPRTSS)

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SUMMARY

The objective of this research is to develop a framework for the Owner's Project Requirements (OPR) for Total Structural Systems (OPRTSS) for structural commissioning of multi-story concrete and/or steel frame structures to: (1) assist owners and commissioning provider to identify and establish a proper task outline for the structural system, (2) identify Structural Engineer's responsibilities and expected performance, and (3) guide Structural Engineer's design teams to the owner's desired final product. This framework is expected to help Owners and developers to establish an OPR that will specify the desired final outcome of the projects to meet the demand of end-users in order to minimize key construction/design issues and litigations, and maximize structural performance. To achieve this goal, the researcher visited construction sites to gather of information about obstacles that the construction industry faces for the structural portion of the project's process. These obstacles are construction/design issues that were identified and addressed to improve quality, and prevent further delays and additional costs, and minimize litigation to the construction industry.

This research analyzed the data collected from various construction sites. The researcher reviewed construction processes. He conducted a comprehensive literature review in the field of building commissioning and interviewed experts and professionals in the construction field for their expertise and past experience in the construction process. He analyzed construction administration documents of projects such as Request For Information (RFI), shop drawings and change orders to identify major construction/design issues that have impacted the structural performance of projects.

The researcher collected comprehensive information by interviewing structural engineers, architects, attorneys, general contractors, and owner representatives. Next, the thesis developed an Owner's Project Requirements framework of the Total Building Commissioning for the Structural System to identify and resolve the main problems that were faced by the industry. Using procedures directed by ASHRAE Guideline 0-2005 as the base and using the established OPR for ASHRAE Guideline 1-2007 and NIBS Guideline 3-2006, the initial framework for Owner's Project Requirements (OPR) was prepared. With the knowledge and agreement of the experts, the identified major construction/design issues were divided in three groups as follows:

- Group one of construction/design issues (also indentified as performance indicators) was identified as those items that were beyond the requirements of applicable building codes or engineering principles, but were demanded by Owners due to today's working environment, new technologies and market demands.
- Group two of construction/design issues was identified as those items that were not clearly defined in the construction documents or project contracts and there was some ambiguity as to who the responsible party is to fulfill those tasks. These construction/design issues were analyzed and defined and added to the OPRTSS for Owners to address in advance.
- Group three of construction/design issues was identified as those items that are related to design and construction quality. These construction/design issues were added to the appendix of this research

as a Guideline to help construction teams to address these construction/design issues during document preparation and construction.

An initial suggested Framework for the Owner's Project Requirements for the Total Structural Systems (OPRTSS) was developed using the initial OPR to identify construction/design issues related to the structural system. A questionnaire was designed per the requirement of the Delphi technique and was sent to a panel of experts for their use to validate the suggested OPRTSS. The answered questionnaires were analyzed and the original OPRTSS was modified to create the final OPRTSS. This corrected OPRTSS was then sent to the same panel of experts for final verification and validation. The intent was to get a consensus of the experts to provide for inclusiveness of the final OPRTSS per the direction of the Delphi technique.

CHAPTER 1

INTRODUCTION

Today, more than ever, litigation and construction problems are growing due to the complexity of construction projects and the demand for optimum project performance. Facing increasing pressure, Owners (capital letter 'O' will be used throughout this research to indicate the focus of the research) must meet client demands, government energy conservation requirements and requirements for sustainability. As the Total Building Commissioning (TBC_X) is gaining acceptance and becoming a required process for federal, state and LEED projects, the required system guidelines are likewise being developed per ASHRAE Guideline 0-2005 recommendations. While several government agencies are in the process of establishing Guidelines for the performance of each system, there has not been any targeted effort to establish Guidelines specifically for the Structural Systems of the total building commissioning.

The Owner's Project Requirements (OPR) is the heart and soul of each commissioned system. The OPR assists commissioning providers and owners to delegate responsibilities and specify the desired outcome of each commissioning system. The objective of this research is to develop a Framework for Owner's Project Requirements (OPR) for Total Structural Systems (OPRTSS) for structural commissioning of multi-story concrete and/or steel frame structures to: (1) assist owners and commissioning providers to identify and establish a proper task outline for the structural system, (2) identify Structural Engineers responsibilities and expected performance, and (3) guide Structural Engineer's design team to the owner's desired final product. This framework is expected to help Owners and developers to establish an OPR that will specify the desired final outcome of the projects to meet the demand of end-users in order to minimize key construction/design issues and litigations, and maximize structural performance.

When the Owner's Project Requirements are not developed, the Owner, designer, contractors, operation and maintenance personnel each interpret the building requirements and their individual responsibilities, from the standpoint of their own specific needs. This often creates a diverse range of views on the constructed project's needs. Unfortunately, while critical for a successful project, the Owner's Project Requirements (OPR) is rarely developed. Developing Owner's Project Requirements (OPR) which reflect the actual needs of the Owner, the end users or occupants, service and operating units, and sometimes the community, is one of the, if not the sole, most important aspect for successful implementation of the Commissioning Process (ASHRAE, Guideline 0-2005).

1.1. Background

Construction background consists of:

1.1.1. Construction Industry and its Processes

The construction industry's activities include site preparation and the building of new structures, as well as additions and modifications to existing structures. The industry also encompasses maintenance, repair and improvements of these structures. Houses, apartments, factories, offices, schools, roads and bridges are among some of the products of the construction industry.

The construction industry is divided into three major segments. The *construction of buildings* segment includes contractors, usually called general contractors, who build residential, industrial, commercial, and other buildings. *Heavy and civil engineering construction contractors* build sewers, roads, highways, bridges, tunnels, and other projects related to the nation's infrastructure. *Specialty trade contractors* perform specialized activities related to all types of construction, such as carpentry, painting, plumbing, and electrical work.

Construction is usually done or coordinated by general contractors, who specialize in one type of construction, such as residential or commercial buildings. They take full responsibility for the complete job, except for specified portions of the work that may be omitted from the general contract. Although general contractors may do a portion of the work with their own crews, they often subcontract the majority of the work to heavy construction or specialty trade contractors.

Specialty trade contractors usually do the work of only one trade, such as painting, carpentry, or electrical work, or of two or more closely-related trades, such as plumbing and heating. Beyond fitting their work to that of the other trades, specialty trade contractors have no responsibility for the structure as a whole. They obtain orders for their work from general contractors, architects or property owners. Repair work is almost always done on direct order from Owners, occupants, architects, or rental agents.

Construction, with 7.2 million wage and salary jobs and 1.8 million self-employed and unpaid family workers, was one of the largest industries in the United States in 2008. About 64 percent of wage and salary jobs in construction were in the specialty trade contractors sector, primarily plumbing, heating and air-conditioning, electrical and masonry. Around 23 percent of these jobs were in residential and nonresidential building construction. The rest were in heavy and civil engineering construction (Table 1.1).

The construction industry has been adversely affected by the credit crisis and economic recession that began in December 2007. Housing prices fell and foreclosures of homes rose sharply, particularly in overbuilt areas of the United States. New housing construction, while still ongoing, dropped significantly. The recession is expected to impact other types of construction as well; for example, retailers are refraining from building new stores and state and local governments are reducing spending. However, as energy costs have risen, companies must decide if it is better to construct a new building or renovate buildings that are currently not energy efficient. "Green construction" is an area that is increasingly popular and involves making buildings as environmentally friendly and energy efficient as possible by using more recyclable and earth-friendly products.

Table 1.1 - Distribution of Wage and Salary Employment in Construction by Industry, 2008 (Employment in thousands) (BLS National Employment Matrix, 2008-18)

Industry	Employment	Percent
Construction, total	7,214.9	100.0
Construction of buildings	1,659.3	23.0
Residential building	832.1	11.5
Nonresidential building construction	827.2	11.5
Heavy and civil engineering construction	970.3	13.4
Utility system construction	451.3	6.3

Table 1.1 Continued

Industry	Employment	Percent
Highway, street, and bridge construction	328.9	4.6
Land subdivision	80.8	1.1
Other heavy and civil engineering construction	109.3	1.5
Specialty trade contractors	4,585.3	63.6
Building equipment contractors	2,023.1	28.0
Foundation, structure, and building exterior contractors	987.8	13.7
Building finishing contractors	912.8	12.7
Other specialty trade contractors	661.6	9.2

Construction Sector

The construction sector is comprised of companies primarily engaged in the construction of buildings or engineering projects (e.g., highways and utility systems), the preparation of sites for new construction, and the subdivision of land for sale as building sites. Construction work may include new work, additions, alterations, or maintenance and repairs. The activities are generally managed at a fixed place of business, but are usually performed at multiple project sites. Production responsibilities for establishments in this sector are usually specified in: (1) contracts with the Owners of construction projects (prime contracts); or (2) contracts with other construction companies (subcontracts).

The construction sector consists of these subsectors:

a) Construction of Buildings:

The Construction of Buildings subsector is comprised of companies and entities primarily responsible for the construction of buildings. The work performed may include new construction, additions, alterations, or maintenance and repairs. The on-site assembly of precut, panelized, and prefabricated buildings and construction of temporary buildings are also included in this subsector. Part or all of the production work for which the companies in this subsector have responsibility may be subcontracted to other construction companies, usually specialty trade contractors.

b) Heavy and Civil Engineering Construction:

The Heavy and Civil Engineering Construction subsector is comprised of companies whose primary activity is the construction of entire engineering projects (e.g., highways and dams); the work performed may include new construction, additions, alterations, or maintenance and repairs. This sector also includes specialty trade contractors, whose primary activity is the production of a specific component for such projects. These specialty trade contractors generally perform activities that are specific to heavy and civil engineering construction projects and are not normally performed on buildings.

c) Specialty Trade Contractors:

The Specialty Trade Contractors subsector is comprised of those companies and entities whose primary activity is performing specific activities (e.g., pouring concrete, site preparation, plumbing, painting, and electrical work) involved in building construction or other activities that are similar for all types of construction, including new work, additions, alterations, maintenance, and repairs. However, specialty trade contractor are not responsible for the entire project. The production work performed by this subsector is usually subcontracted from companies of the general contractor type or operative builders, particularly in remodeling and repair construction; work may also be done directly for the Owner of the property. Specialty trade contractors usually perform most of their work at the construction site, although they may have off-site shops where they perform prefabrication and other work. Companies and subcontractors primarily engaged in preparing sites for new construction are also included in this subsector (http:\\www.bls.gov, 2010).

Owner's Perspective

By adopting the viewpoint of the Owners, attention can be focused on the complete process of *project management* for constructed facilities rather than the historical roles of various specialists, such as planners, architects, engineering designers, constructors, fabricators, material suppliers, financial analysts, and others. Owners desire completion of projects in a timely, cost-effective fashion which differs from the perspectives of other parties. Some profound implications for the objectives and methods of project management result from this perspective.

1.1.1.2. Project Life Cycle

The acquisition of a constructed facility usually represents a major capital investment, whether its Owner happens to be an individual, a private corporation or a public agency. Since the commitment of resources for such an investment is motivated by market demands or perceived needs, the facility is expected to satisfy certain objectives within the constraints specified by the Owner and relevant regulations (Hendrikson, 1998). See Figure 1.1 for project processes.

Since an Owner is essentially acquiring a facility on a promise in some form of agreement, it would be wise for any Owner to have a clear understanding of the acquisition process in order to maintain firm control of the quality, timeliness and cost of the completed facility.

From the perspective of an Owner, the project life cycle for a constructed facility may be illustrated schematically in Figure 1.2. Essentially, a project is conceived to meet market demands or needs in a timely manner. Various possibilities may be considered in the conceptual planning stage, and the technological and economic feasibility of each alternative should be assessed and compared in order to select the best possible project. After the scope of the project is clearly defined, detailed engineering design will provide the blueprint for construction. Then a definitive cost estimate will serve as the baseline for cost control. After the construction is completed, there is usually a brief period of start-up or shake-down of the constructed facility when it is first occupied, as shown in Figure 1.3.

By examining the project life cycle from an Owner's perspective, we can focus on the proper roles of various activities and participants in all stages regardless of the contractual arrangements for different types of work. The project life cycle may be viewed as a process through which a project is implemented from cradle to grave. This process is often very complex; however, it can be separated into several stages, as indicated by the general outline in Figure 1.2. The solutions at various stages are then integrated to obtain the final outcome. Although each stage requires different expertise, each usually includes both technical and managerial activities in the *knowledge domain* of the specialist. The Owner may choose to separate the entire process into more or less stages based on the size and nature of the project, and thus obtain the most efficient result in implementation.

Very often, the Owner retains direct control of work in the planning and programming stages, but increasingly outside planners and financial experts are used as consultants because of the complexities of projects. In making choices, Owners should be concerned with the life cycle costs of constructed facilities rather than simply the initial construction costs. Saving small amounts of money during construction may not be worthwhile if the result is much larger operating costs or not meeting satisfactory functional requirements for the new facility. Thus, Owners must be very concerned with the quality of the finished product as well as the cost of construction itself. Since facility operation and maintenance is a part of the project life cycle, the Owner's expectation to satisfy investment objectives during the project life cycle will require consideration of the cost of operation and maintenance. Therefore, the facility's operating management should also be considered as early as possible, just as the construction process should be kept in mind at the early stages of planning and programming (Hendrikson, 1998).

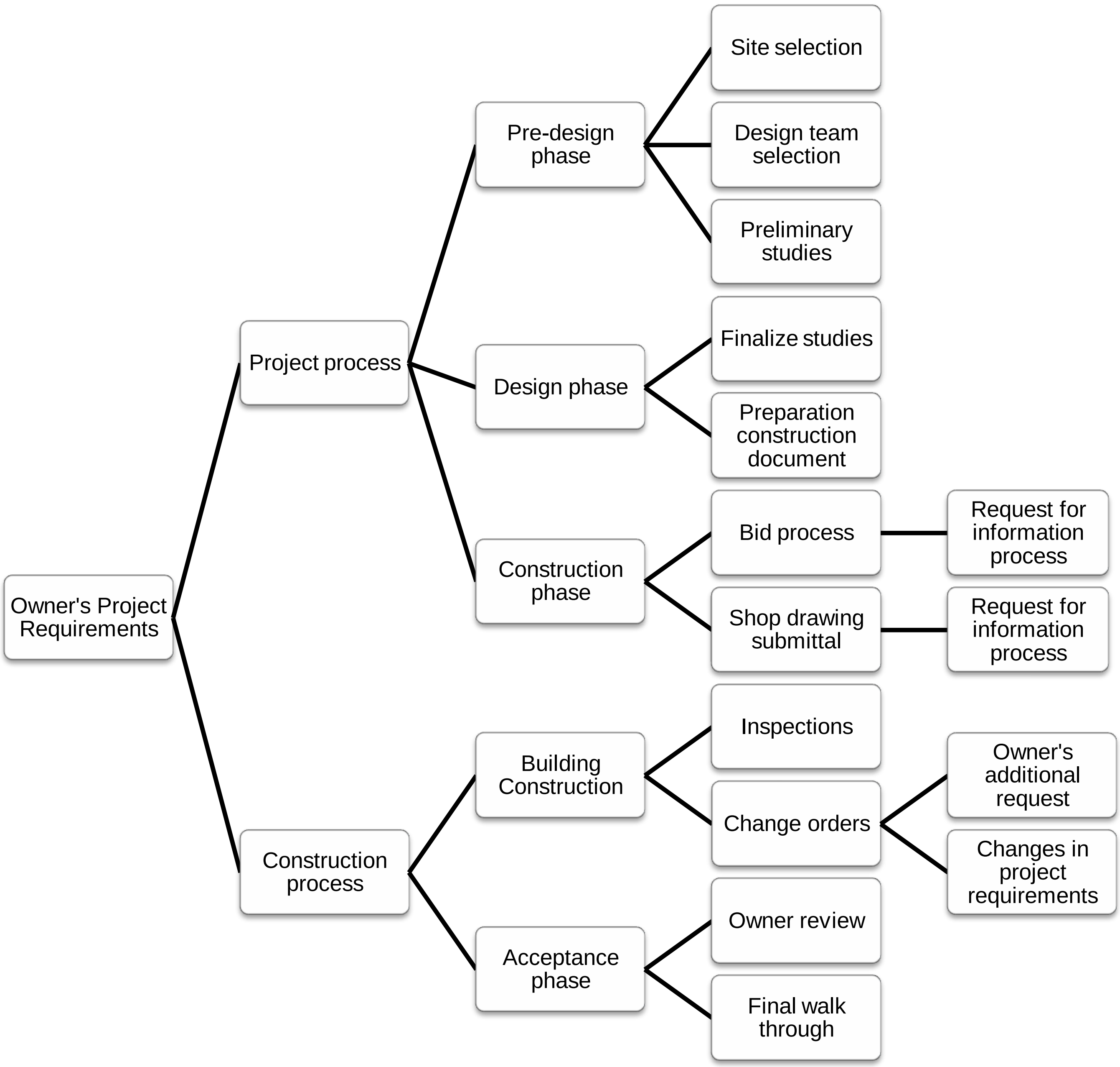


Figure 1.1 Project Process

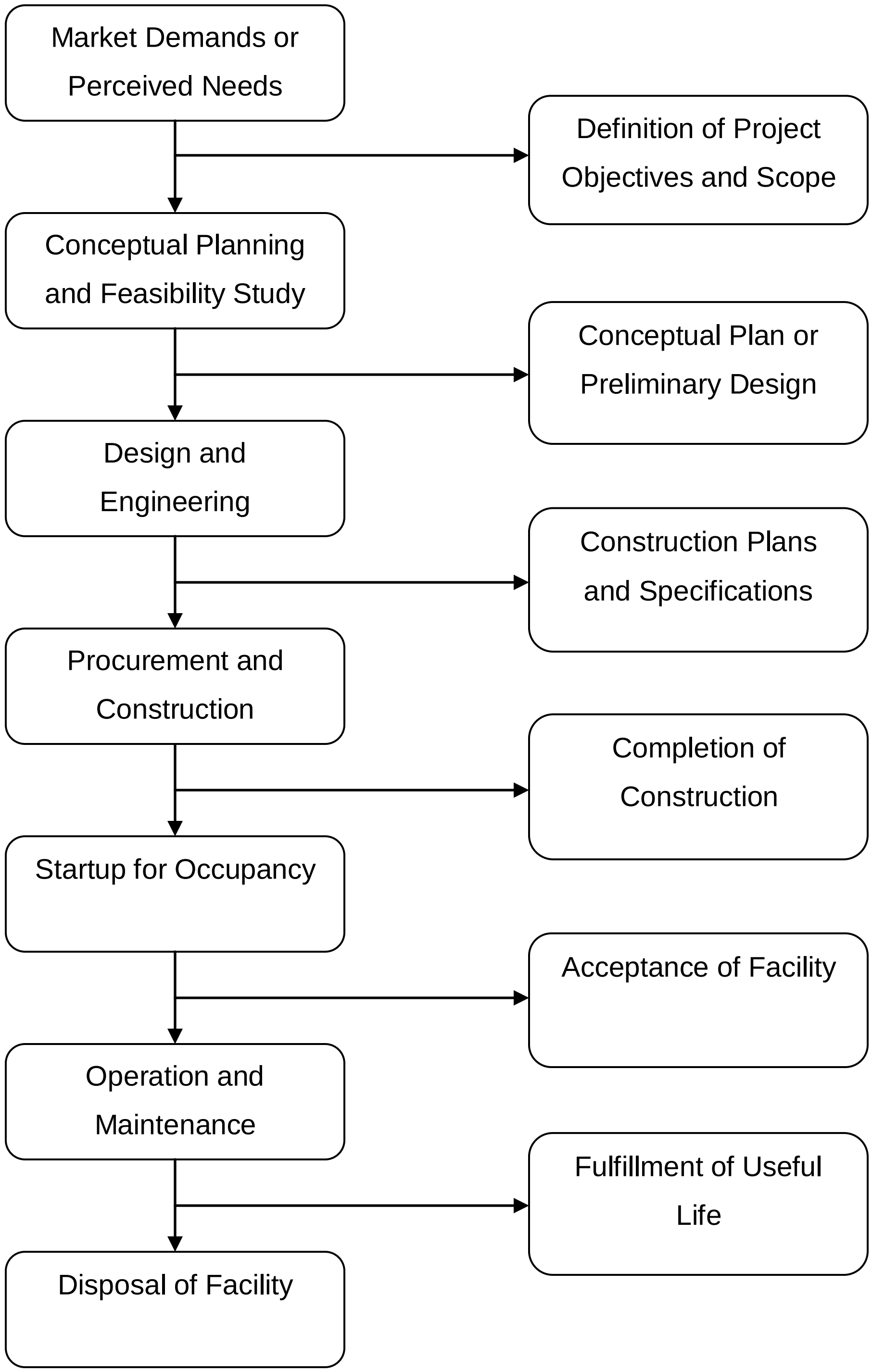


Figure 1.2 Project Life Cycle of a Constructed Facility.

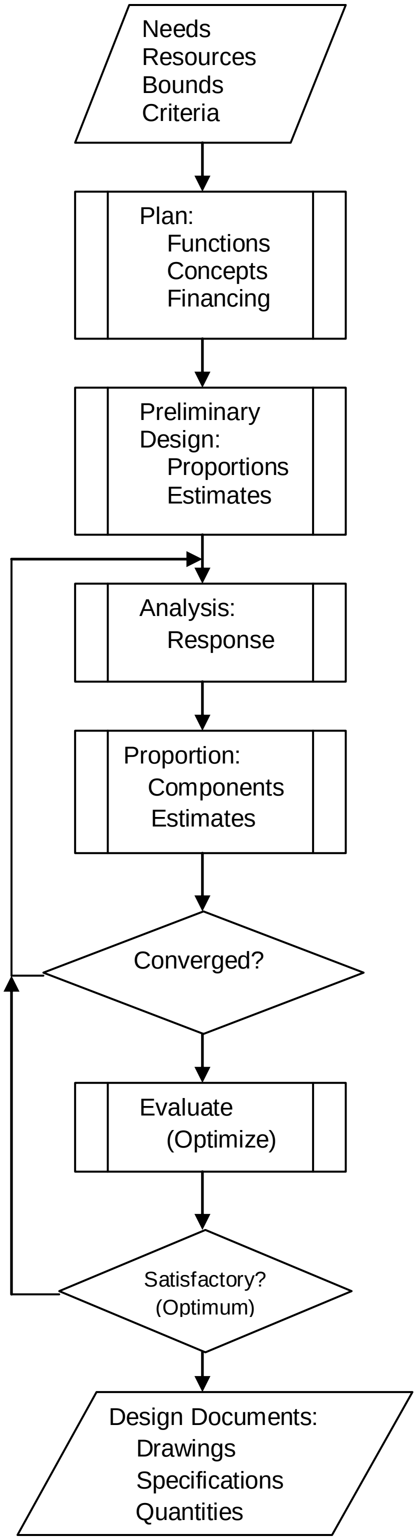
1.1.2. Design and Construction Process

As the project moves from conceptual planning to detailed design, the design process becomes more formal. In general, the actions of formulation, analysis, search, decision, specifications and modifications still hold, but they represent specific steps with less random interactions in detailed design. Thus, the formalized design methodology can be applied to a variety of design problems. A detailed analogy of the schematic diagrams of the structural design process and of the computer program development process is shown in Figure 1.3. At varying levels of detail, a project manager must ensure that these inputs are effectively coordinated to achieve an efficient construction process.

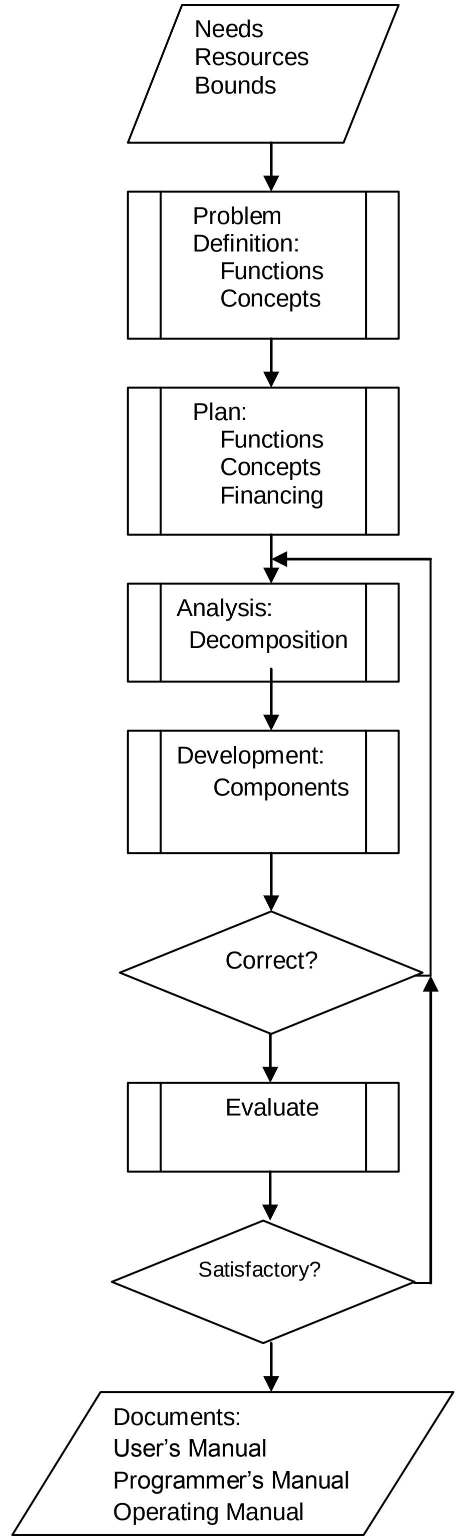
This coordination involves both strategic decisions and tactical management in the field. For example, strategic decisions about appropriate technologies or site layout are often made during the process of construction planning/pre-design phase. During the course of construction, foremen and site managers will make decisions about work to be undertaken at particular times of the day based upon the availability of the necessary resources of labor, materials and equipment. Without coordination among these necessary inputs, the construction process will be inefficient or stop altogether (Hendrikson, 1998).

Selection of Professional Services

When an Owner decides to seek professional services for the design and construction of a facility, he is confronted with a broad variety of choices. The types of services selected depend to a large degree on the type of construction and the Owner's



Schematic diagram of structural design process



Schematic diagram of computer program development process

Figure 1.3 - An Analogy between Structural Design and Computer Program Development Process – (*Structural Engineering Handbook,* 2nd Ed., McGraw-Hill Book Company, New York, 1979.)

experience dealing with various professionals in the previous projects undertaken by the firm. Generally, several common types of professional services may be engaged either separately or in some combination by the Owners (Hendrikson, 1998). The primary professional services are described in more detail below.

Financial Planning Consultants

At the early stage of strategic planning for a capital project, an Owner often seeks the services of financial planning consultants, such as certified public accounting (CPA) firms, to evaluate the economic and financial feasibility of the constructed facility. This consultation is important with respect to various provisions of federal, state and local tax laws which may affect the investment decision. Investment banks may also be consulted on various options for financing the facility, in order to analyze their long-term effects on the financial health of the owner organization (Hendrikson, 1998).

Architectural and Engineering Firms

Traditionally, the Owner engages an architectural and engineering (A/E) firm or a consortium of professionals as technical consultants in developing a preliminary design. After the engineering design and financing arrangements for the project are completed, the Owner will enter into a construction contract with a general contractor either through competitive bidding or negotiation. The general contractor will act as a constructor and/or a coordinator of a large number of subcontractors who perform various specialties for the completion of the project. The A/E firm completes the design and may also provide on-site quality inspection during construction. Thus, the A/E firm acts as the prime professional on behalf of the Owner and supervises the construction to ensure satisfactory results. This practice is most common in building construction. In the past two decades, this traditional approach has become less popular for a number of reasons, particularly for large-scale projects. The A/E firms, which are engaged by the Owner as the primary professionals for design and inspection, have become more isolated from the construction process. This has occurred because of pressures to reduce fees to A/E firms, the threat of litigation regarding construction defects and the lack of knowledge of new construction techniques on the part of architect and engineering professionals. Instead of preparing a construction plan along with the design, many A/E firms are no longer responsible for the details of construction, nor do they provide periodic field inspection in many cases. Such firms will often place a prominent disclaimer of responsibilities on any shop drawings they may check, and they will often regard their representatives in the field as observers rather than inspectors. Thus, the A/E firm and the general contractor on a project often become antagonists who are looking after their own competing interests.

As a result, even the constructability of some engineering designs may become an issue of contention. To carry this protective attitude to the extreme, the specifications prepared by an A/E firm for the general contractor often protect the interest of the A/E firm at the expense of the interests of the Owner and the contractor. In order to reduce the cost of construction, some Owners introduce *value engineering*, which seeks to reduce the cost of construction by soliciting a second design that might cost less than the original design produced by the A/E firm. In practice, the second design is submitted by the contractor after receiving a construction contract at a stipulated sum, and the cost savings resulting from the redesign is shared by the contractor and the Owner. The contractor is then able to absorb the cost of redesign from the profit in construction or to reduce the construction cost as a result of the re-design. If the Owner had been willing to pay a higher fee to the A/E firm or to better direct the design process, the A/E firm might have produced an improved design which would cost less initially. Regardless of the merit of value engineering, this practice has undermined the role of the A/E firm as the prime professional acting on behalf of the Owner to supervise the contractor (Hendrikson, 1998).

Design/Construction Firms

A common trend in industrial construction, particularly for large projects, is to engage the services of a design/construct firm. By integrating design and construction management in a single organization, many of the conflicts between designers and constructors might be avoided. In particular, designs will be closely scrutinized for their constructability. However, an Owner engaging a design/construct firm must ensure that the quality of the constructed facility is not sacrificed by the desire to reduce the time or the cost for completing the project. Also, it is difficult to make use of competitive bidding in this type of design/construct process. As a result, Owners must be relatively sophisticated in negotiating realistic and cost-effective construction contracts.

One of the most obvious advantages of the integrated design/construct process is the use of *phased construction* for a large project. In this process, the project is divided into several phases, each of which can be designed and constructed in a staggered manner. After the completion of the design of the first phase, construction can begin without waiting for the completion of the design of the second phase, etc. If proper coordination is exercised, the total project duration can be greatly reduced. Another advantage is to exploit the possibility of using the *turnkey* approach, whereby an Owner can delegate all responsibility to the design/construct firm which will deliver to the

Owner a completed facility that meets the performance specifications at the specified price (Hendrikson, 1998).

Professional Construction Managers

In recent years, a new breed of construction managers (CM) offers professional services from the inception to the completion of a construction project. These construction managers usually come from the ranks of A/E firms or general contractors, who may or may not retain dual roles in the service of the Owners. In any case, the Owner can rely on the service of a single prime professional to manage the entire process of a construction project. However, like the A/E firms of several decades ago, construction managers are appreciated by some Owners but not by others. Over time, some Owners find that the construction managers, too, may try to protect their own interest instead of that of the owners when the stakes are high.

However, it should be obvious to all involved in the construction process that the party which is required to take greater risk demands greater rewards. If an Owner wants to engage an A/E firm on the basis of low fees instead of established qualifications, it often gets lower-quality services. In the same way, if the Owner wants the general contractor to bear the cost of uncertainties in construction, such as foundation conditions, the contract price will be higher even if competitive bidding is used in reaching a contractual agreement. Without mutual respect and trust, an Owner cannot expect that construction managers can produce better results than other professionals. Hence, an Owner must understand his own responsibility and the risk he wishes to assign to himself and to other participants in the process (Hendrikson, 1998).

Operation and Maintenance Managers

Although many Owners keep a permanent staff for the operation and maintenance of constructed facilities, others may prefer to contract such tasks to professional managers. It is common to find in-house staff for operation and maintenance in specialized industrial plants and infrastructure facilities. It is also common to use outside managers under contracts for the operation and maintenance of rental properties, such as apartments and office buildings. However, there are exceptions to these common practices. One example is maintenance of public roadways which can be contracted to private firms. In any case, managers can provide a spectrum of operation and maintenance services for a specified time period in accordance to the terms of contractual agreements. Thus, the Owners can be spared the provision of in-house expertise to operate and maintain facilities (Hendrikson, 1998).

Facility Management:

As a logical extension for obtaining the best services throughout the project life cycle of a constructed facility, some Owners and developers are receptive to adding strategic planning at the beginning. They use facility maintenance as a follow-up to reduce space-related costs in their real estate holdings. Some architectural/engineering firms and construction management firms with computer-based expertise, together with interior design firms, are offering front-end and follow-up services in addition to more traditional services in design and construction. This spectrum of services is described in *Engineering News-Record* (now *ENR*) as follows: (ENR, April 4, 1985).

Construction Contractors

Builders who supervise the execution of construction projects are traditionally referred to as *contractors*, or more appropriately called *constructors* (Hendrikson, 1998). There are several types of construction contractors. Each is described in more detail below:

General and Specialty Contractors:

The function of a general contractor is to coordinate all tasks in a construction project. Specialty contractors include mechanical, electrical, foundation, excavation, and demolition contractors among others. They usually serve as subcontractors to the general contractor of a project.

Material and Equipment Suppliers:

Major material suppliers include specialty contractors in structural steel fabrication and erection, sheet metal, ready mixed concrete delivery, reinforcing steel bar detailers, roofing, glazing, etc.

Third Party-led Total Building Commissioning:

The practice of Total Building Commissioning has gained a lot of attention in recent years. Owners and managers are requiring implementation of commissioning in construction projects to ensure the proper performance of facilities as-a whole, as well as the quality of individual building systems throughout the life cycle of the facility.

Shakoorian (2006) investigated the effect of different procurement options on the outcome of a construction project, and proved Owner-led Commissioning presented a higher performance rating than Designer-led Commissioning (Shakoorian, 2006).

1.1.3. Commissioning and its history

Historically, the term “commissioning” referred to a series of activities attempting to safeguard naval vessels, so they would not face any operational failures (Mauro, 2005). However, the concept of commissioning in buildings did not start until the 1950s in Europe, when increasing energy prices provided a major driving force for improving the overall efficiency of building systems (FMI, 2001). At the time, commissioning referred to test and balance activities, performed at the end of construction and before building occupancy, to ensure proper operation of a building system.

Total building commissioning is the quality process for achieving, validating and documenting that the facility and its systems and assemblies are planned, designed, installed, tested and capable of being operated and maintained to perform in conformity with the needs of the client and the design intent. Traditional building commissioning is used to validate only a portion of the total system being constructed (http://www.bca.org, 2010). The first commissioning effort in North America was undertaken during the 1970s, when Alberta Public Works Supply and Services (APWSS) in Canada started to develop coordinated efforts in systems’ start-up and turnover on all of its major projects (Dunn, 1994).

The National Institute of Building Sciences (NIBS) is spearheading an ongoing effort to develop Guidelines for the commissioning of a range of building systems to achieve some of these goals (NIBS, 2010). The commissioning of a single system has developed to:

a) Total Building Commissioning (either continuous or periodic), which covers all building systems,

b) Retro-Commissioning that will commission buildings that are built and have not gone through any commissioning and,

c) Re-commissioning that will commission buildings at a certain time period that have already gone through Building Commissioning (See definitions for Re-Commissioning and Retro-Commissioning in Appendix B).

NIBS have initiated technical supporting Guidelines for various building systems that will be developed by the working groups within various organizations that are members of the NIBS Commissioning Process Guideline Committee (NIBS, 2010). The purpose of these Guidelines is to describe the commissioning process capable of verifying that a facility and its systems meet the Owner's Project Requirements (OPR). The process, methods, and documentation requirements in these Guidelines describe each phase of the project delivery and identify the associated commissioning process from pre-design through occupancy and operation, without attention on a specific element, assembly, or system.

There are 13 (including Guideline 0-2005) Guidelines established by NIBS that are either developed, under development or will be developed by using format developed by ASHRAE Guideline 0-2005 (BCx, 2010). Guideline 2 of the NIBS Guidelines has been assigned to cover Structural Systems of buildings (BCx, 2010). As of today, no research or studies exist for the commissioning of the Structural Systems of buildings or projects requiring construction of the main supporting systems using various building construction material such as concrete, steel, masonry, wood, and horizontal and vertical support systems such as diaphragms, frames, and shear walls. Although several institutions are in the process of establishing certain Guidelines for the performance of each system, there has not been any substantial activity in the Structural Systems of the Total Building Commissioning plan.

Need for structural commissioning of structures

The traditional structure of a new construction team in terms of communications is vertical, rather than circular; therefore it lacks any real form of checks and balances. Sub-consultants to the Architect do not have reporting responsibility to the Owner, leaving issues to be resolved backwards through the line of command. It can take quite some time for an issue to be escalated back up through the ladder, leaving an Owner/developer with an issue that has been festering for weeks or months. This lag time now compromises the project schedule, budget, and, ultimately, the completion of the project as desired. The Commissioning Authority (CA or CxA) serves as the missing link in the circular chain of communication (http://www.bca.org, 2010). Commissioning needs to be viewed as a quality control, verification and validation process. With this view in mind, there is no reason why a generally static element such as a foundation, floor, column, wall, frame roof or partition cannot be "commissioned" (http://www.bca.org, 2010).

Who should do building commissioning?

Typically, the Owner/developer contracts directly with the Commissioning Authority, which prohibits any potential to "bite the hand that feeds," which is perpetuated in the traditional project hierarchy. The Commissioning Authority documents the sub-consultant's findings, communicates these directly to the Owner, and verifies the findings in accordance with the Owner's Project Requirements (OPR), or provides recommendations for alternate solutions to the project team, as necessary. Shakoorian shows this method would be the optimum arrangement (Shakoorian, 2006).

Third-party Commissioning is the most widely used model in the industry. But, at the same time, it is suspected that other Commissioning Delivery Systems may be more appropriate (Dunn, 1994) (Prowler, 2003). For example, even though supporters of Third-party Commissioning argue that an independent, third-party commissioning provider is the only viable way to fully represent the Owner's interests in the project, others question the ability of this model to create the collaborative environment that is essential in realizing the true value of the commissioning practice (Shakoorian, 2006). It has been suggested that an Architect/Engineer or the General Contractor, performing the commissioning services, benefits the project, since these parties already have full knowledge about the project and can use the commissioning process to improve the quality of their services (Shakoorian, 2006).

Benefits of Structural Systems commissioning

Commissioning for Structural Systems has not been utilized in the building industry. There are not many projects that have gone through any major Structural Systems commissioning. In order to evaluate the effect and the benefits of building commissioning, several projects that have gone through building commissioning for specific systems such as HVAC Systems, Mechanical Systems, Electrical Systems and Lighting Control Systems. These evaluations were reviewed to document the benefits of building commissioning. A list of these projects is recorded in Appendix D. The review of commissioning reports of these buildings indicated that the commissioning of building systems has:

- Improved system performance by ensuring that equipment and systems are properly designed, installed, maintained, and optimized to work together.
- Reduced change orders and improved contractor performance and awareness.
- Improved overall construction process and project turnover.
- Made contractors more aware of the quality of their work as results of testing and monitoring.
- Caused better project communication and facilitated the conflict resolution process.
- Improved energy efficiency.
- Reduced building operating costs.
- Improved indoor air quality, and reduced the Owner’s liability relative to occupant health and comfort.
- Made significant extension of equipment/systems life cycle.
- Improved building operation and maintenance.
- Increased worker productivity.
- Increased occupant and Owner satisfaction.

Current status of building commissioning

Commissioning became a major component of several national programs for improving the quality of the building environment, such as the Department of Energy's

Rebuild America and the U.S. Green Building Council's LEED rating system (The key to quality assurance., 2009). Currently, implementation of Building Commissioning is experiencing exponential growth in the construction industry.

General Services Administration (GSA) requires that all new construction and major renovation projects, starting in 2006 and after, adopt some form of Building Commissioning as their quality-assurance tool (Eakin, 2002). The National Aeronautics and Space Administration (NASA) has also recognized Total Building Commissioning as the best practice, and has adopted this processes to improve the performance of its buildings (NASA, 2001).

Building commissioning is rapidly becoming standard practice in a wide range of facilities, including, but not limited to, data centers, laboratories, schools, hospitals, and institutional and office buildings. It is also expected that the emergence of new types of Project Delivery Systems, such as Design-Build, which define a demand/supply relationship between Owners and service providers, adds to the importance of Building Commissioning. The PDS serves as a comprehensive tool to ensure the Owner's requirements are met in the project (Shakoorian & Sadri, 2004).

The Guidelines

Development of Guidelines for the Building Commissioning Process began in the United States formally in 1982 when the American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) formed a committee to document the best practices to deliver facilities that performed according to the Owner's Project Requirements (ASHRAE-Guideline 0-2005).

ASHRAE published its original commissioning Guideline in 1989, updated a version in 1996 and formed it as a Guideline 0-2005. The Commissioning Process detailed in these Guidelines is the result of experience on projects requiring that systems and assemblies worked from the first day the project was turned over to the Owner. This Commissioning Process is further based upon experience with projects that met the requirements of Owners, occupants, users of processes, and facility operating-maintenance-service organizations at a high level of satisfaction and that reduced the cost to deliver the project (ASHRAE, Guideline 0-2005). Guideline 0-2005 was published to address underlying quality based commissioning processes without reference to a specific area, to describe the Commissioning Process capable of verifying that a facility and its systems meet the OPR and it will update it every five years (ASHRAE, Guideline 0-2005). Guideline 0-2005 is the main instrument for development of the other Guidelines. For definitions of certain terminology, see Appendix B. The current status and progress of Guidelines is detailed in Appendix C.

1.2. The Research Problem

In today's market, Architects must satisfy the demands of Owners who are under intense competition to increase their occupancy and satisfy tenants. Due to an increase in both project and building complexity, construction problems are rising. These problems are also exacerbated by a lack of proper communication between the Owners, Architects and other design team members responsible for preparing final construction documents that meet Owner's Project Requirements (OPR). This lack of communication is often due to improper design or not having a clear objective by the design team as what the Owner's Project Requirements are before construction begins. This research attempts to account for these challenges by establishing a specific framework for Owner's Project Requirements. This framework will focus specifically on the structural system, as outlined in Guideline 2 of Total Building Commissioning.

1.2.1. Research Objectives and Scope

The objective of this research is to develop a framework for Owner's Project Requirements (OPR) for the Total Structural Systems (OPRTSS) for structural commissioning of multi-story concrete and/or steel frame structures to: (1) assist owners and commissioning providers to identify and establish a proper task outline for the structural system, (2) identify Structural Engineer's responsibilities and expected performance, and (3) guide Structural Engineer's design team to the owner's desired final product. This framework is expected to help Owners and developers to establish an OPR that will specify the desired final outcome of the projects to meet the demand of end-users in order to minimize key construction/design issues and litigations, and maximize structural performance.

1.2.2. Study Hypothesis

The hypothesis of this study is defined as the following:

> *There are identifiable owner's project requirements, which when violated, result in design and construction issues that impact structural performance of a project, during procurement of concrete or steel framed projects. These requirements are not*

currently defined at the pre-design stage of projects by contracts, applicable building codes or engineering principles.

1.3. Research Outline

The following paragraphs outline the steps taken in this study to address the research problem described in the previous section.

Chapter 2 - Comprehensive literature and document review - Although the practice of building commissioning has existed for more than 25 years, the concept of Total Building Commissioning is still at a very early stage of development. Therefore, it was important to study the existing literature on building commissioning and Total Building Commissioning, in order to explore the evolution and state-of-the-art developments of this practice (Shakoorian, 2006). ASHRAE Guideline 0-2005 and established ASHRAE Guideline 1-2007 and NIBS Guideline 3-2006, types of building system commissioning as well as responsible parties were reviewed to familiarize the researcher with all aspects of commissioning and commissioning teams.

Construction site meetings were conducted and the construction process was observed. Various structural firms were visited and their construction administration documents, such as approved shop drawings, request for information (RFIs), test results and construction problems were reviewed. Structural Engineers involved directly with construction administration were interviewed, to make the researcher more familiar with the type of construction problems, lack of required information and construction methods which were problematic. These documents were reviewed to establish a preliminary framework for items that are commonly missed on construction documents, most commonly requested information, and construction/design issues that impact structural performance.

Various construction firms were visited and developers/owners, as well as general contractors, were interviewed to investigate the common construction/design issues that developers and general contractors face that affect the structural performance of the construction process.

Chapter 3 - The results of the observations, literature study, documents investigations and interviews performed in Chapter 2 are used to identify construction/design issues in order to develop the initial framework for the Owner's Project Requirements for the Total Structural Systems (OPRTSS) of Total Building Commissioning. A questionnaire was prepared and sent to a panel of experts to identify the construction/design issues that impact structural performance for preparation of the framework.

Chapter 4 – Chapter 4 is aimed at gathering additional items that would impact structural performance of a project.

Chapter 5 – Chapter 5 is aimed at assessing the performance of each section of the suggested OPRTSS. The results of the surveys conducted per Delphi Method are discussed in depth in this chapter.

Chapter 6 - The Suggested framework for the Owner's Project Requirements for the Total Structural Systems (OPRSS) of multi-story concrete and steel structures as a part of Total Building Commissioning was developed. A questionnaire was prepared for verification and validation of the suggested OPRTSS. Questionnaires were sent to a panel of experts which included 38 registered professional structural Engineers. After validation of OPRTSS, the corrected version of OPRTSS was sent to the respondents for final review and approval.

Chapter 7 - Summary, conclusions, and recommendations for future research.

1.4. Expected Benefits of the Research

The primary expected benefit of this research is the framework for the Owner's Project Requirements for the Total Structural Systems (OPRTSS). The result of this research is expected to help the Owner identify the desired final outcome of the structure, in order to meet both his/her and market demands. As a result, this framework is expected also to help service providers to better structure commissioning services with other disciplines in the construction process and provide the building Owners with the highest value. The OPRTSS is expected to reduce construction delays, confusion in the construction process and construction litigations, and maximizes the Structural Engineer's ability to prepare construction documents in a timely manner. Finally, the literature review performed in Chapter 2 provides a comprehensive review of building commissioning literature. The review maps the evolution of this concept from a quality-control practice to a quality-assurance method.

CHAPTER 2
LITERATURE AND DOCUMENT REVIEW

2.1 Purpose

The purpose of this chapter is to provide a comprehensive review of the existing literature to establish a point of departure for this research. This literature study is compromised of two sections. The first section focuses on Building Commissioning. The objective is to investigate the evolution of this concept, identify state-of-the-art research and practices, and facilitate the creation of the Owner's Project Requirements (OPR) for other Guidelines. This investigation is crucial in determining a standard definition and a foundation for Building Commissioning among the various views and perceptions existing in the industry

The second part of this chapter reviews the existing literature and documents on process performance measurement. The purpose of this section is to look at the evolution of performance measurement, in general, as well as the application of this concept in construction. This investigation provides an avenue to establish a framework for the OPR for the structural system.

2.2 *Building Commissioning*

This section provides an overview of Building Commissioning and existing state-of-the-art research and practice. This overview is further used to establish the systematic framework for the Owner's Project Requirements (OPR). The literature reviewed in this section was collected through several sources. First, peer-reviewed journals were obtained through engineering databases, including ASCE, and Galileo. A small number of papers were identified through these databases, indicating a current lack of systematic research on the subject of Building Commissioning. Another source was the proceedings of the National Conferences on Building Commissioning (NCBC). Held annually since 1992, NCBC is the leading forum for the exchange of information and ideas in the area of Building Commissioning. Finally, some useful information regarding the practice of Building Commissioning was found through Google's search engine and existing Guidelines such as ASHRAE Guideline 0-2005, ASHRAE Guideline 1-2007, and NIBS Guideline 3-2006. This information was used after careful verification of its source reliability.

2.2.1. Background

Historically, the term "commissioning" referred to a series of activities attempting to safeguard naval vessels, so they would not face any operational failures (Mauro, 2005). However, the concept of commissioning in buildings did not start until the 1950s in Europe, when increasing energy prices provided a major driving force for improving the overall efficiency of building systems (FMI, 2001).

At the time, commissioning referred to test and balance activities, performed at the end of construction and before building occupancy, to ensure proper operation of a building system. Total building commissioning is a quality process for achieving, validating and documenting that the facility and its systems and assemblies are planned, designed, installed, tested and capable of being operated and maintained to perform in conformity with the needs of the client and the design intent. Traditional building commissioning is used to validate only a portion of the total system being constructed (http://www.bca.org, 2010).

The first commissioning effort in North America was undertaken during the 1970s, when Alberta Public Works Supply and Services (APWSS) in Canada started to develop coordinated efforts in systems' start-up and turnover on all of its major projects (Dunn, 1994).

The National Institute of Building Sciences (NIBS) is spearheading an ongoing effort to develop Guidelines for the commissioning of a range of building systems to achieve some of these goals (NIBS, 2010). The commissioning of a single system has evolved to:

- Total Building Commissioning (either continuous or periodic), which covers all building systems,
- Retro-Commissioning that will commission buildings that are built, but have not gone through any commissioning and
- Re-commissioning that will commission buildings at a certain time period that have already gone through Building Commissioning (See definitions for Re-Commissioning and Retro-Commissioning in Appendix B).

NIBS have initiated technical supporting Guidelines for various building systems that will be developed by the working groups within various organizations that are members of the NIBS Commissioning Process Guideline Committee (NIBS, 2010). The purpose of these Guidelines is to describe the commissioning process capable of verifying that a facility and its systems meet the Owner's Project Requirements (OPR). The process, methods and documentation requirements in these Guidelines describe each phase of the project delivery and identify the associated commissioning process from pre-design through occupancy and operation, without attention on a specific element, assembly or system. There are 13 (including Guideline 0-2005) Guidelines established by NIBS that are either developed, under development or will be developed by using format developed by ASHRAE Guideline 0-2005 (BCx, 2010). Guideline 2 of the NIBS Guidelines has been assigned to the Structural Systems that will cover the Structural Systems of buildings (Total Building Commissioning Handbook).

As of today, no research or studies exist for the commissioning of the Structural Systems of buildings. Although several institutions are in the process of establishing certain Guidelines for the performance of each system, there have not been any activities in the Structural Systems of the Total Building Commissioning plan.

Evolution of Building Commissioning Practice as Quality Assurance System

In the first National Conference on Building Commissioning in 1992, Portland Energy Conservation Inc. (PECI) a major advocate of the commissioning practice, defined commissioning as: (Coleman, 2004)

> a systematic process – beginning in the design phase, lasting at least one year after project closeout, and including the training of operating staff – of ensuring, through documented verification, that all building systems perform interactively according to documented design intent and the Owner's operational needs.

This definition introduced two major shifts from the traditional view of Building Commissioning. First, the focus of Building Commissioning was extended to the overall performance of building systems and their interactions, as opposed to traditional practice, which only included the HVAC systems (Maisey, 2004). The second shift, which was more important, was the introduction of Building Commissioning as a *quality assurance* tool. In other words, Building Commissioning was defined as a set of activities that span over the whole life-cycle of a project, and are aimed at ensuring the adherence to Owner-operational needs at any stage of the process. In this approach, Building

Commissioning is defined as a two-step process. In the first step, which is performed at the early stages of the project, the Owner's project requirements are identified and documented. In the second stage, which starts from design and continues through occupancy, deliverables are constantly checked and tested against project requirements to ensure that they meet the Owner's criteria.

In recent years, this total quality management view of Building Commissioning has gained a lot of momentum in the construction industry. Building Commissioning is being viewed more as a comprehensive tool which ensures the building as a whole meets the needs of the users, and *all* building systems operate as expected (Dorgan, 2000).

Although real-life examples of implementation of comprehensive commissioning processes do not exist, commissioning is increasingly being used in the quality assurance of building systems other than HVAC. Examples of building systems which are being commissioned today include: Building Shell and Envelope; Communication Systems; Fire and Safety Systems; and Security Systems (Levin, 1989) (Parzych, 2005) (Tseng P. C., 2005).

Types of Building Commissioning

The commissioning of a single system has evolved to: (See Appendix B for definitions). (Hague, 2000)

- *Building Commissioning*
- *Retro Commissioning*
- *Re-Commissioning*
- *Continuous Commissioning*

- *Total Building Commissioning*

Since there has not been any activity on structural system commissioning, it is anticipated that structural system commissioning will fall under Total Building Commissioning, which, as a quality assurance instrument, addresses all building systems through the entire life-cycle of the facility.

Commissioning Principles

Regardless of the extent to which the commissioning process is applied to a project, there are four overarching principles in the Commissioning Process that begin at project inception and continue through Occupancy and Operations.

1. Establish Measureable Project Performance Requirements

As projects progress through successive Design Stages, design teams establish Owner's Project Requirements (OPR), project work scopes and design solutions that meet the needs of the operation that will be housed in the new facility. It is the task of the commissioning process to establish *measureable dynamic system performance requirements* that can be definitively measured through field testing methodologies. These criteria, properly documented and measured, ultimately form the basis for the projects final acceptance.

Since building performance decisions are successively refined over the course of a project's life cycle, it is imperative that these 'measureable requirements' be refined and documented at the same time. During the pre-design and design phases of a project, the critical objectives of the commissioning process include:

- Develop Owner's Project Requirements (OPR)
- Define Dynamic Performance Requirements of the Project, including:

    - Environmental Control Criteria
    - Response to Threats, Risks, and Failures
    - Static and Dynamic Performance Requirements
- Review Design Documents for Compliance with the OPR
    - Design Narrative (Basis of Design) Document
    - Plans & Specifications
- Document Design Development Decisions
    - Deviations for OPR or Design Narrative
    - Value Engineering Decisions & Consequences
- Document the Process
    - Develop & Maintain a Project Commissioning Plan
    - Develop a Commissioning Specification

2. Plan and Execute the Commissioning Process

Since Commissioning is a collaborative process involving multiple parties with potentially conflicting interests, it is critical that the process be well-planned, documented and communicated to all project team members. Planning is accomplished through development and maintenance of the project Commissioning Plan. Planning must include:

- Clear Roles and Responsibilities for all Team Members
- Well Defined Commissioning Work Scope and Deliverables
- Project Commissioning Schedules
- Effective Inspection and Testing Plans of Pre-Functional and Functional Test Plans

- Integrated System Test Plans
- Special testing needs for unique or innovative assemblies
- Clear definition of team member testing responsibilities

- Clear Commissioning Specifications consistent with the Project Commissioning Plan
- Clear Definitions of Training Requirements to Support Long-Term Sustainability

3. Verify and Document Compliance with Requirements

Commissioning serves as the historical record of both the expectations for project performance and the performance achieved in the construction process. Commissioning documentation should provide a record of standards of performance for building systems and that performance achieved in the delivered facility. Commissioning documentation should include:

- A clear history of Project Development, Execution and Turnover
- A definitive record of all inspections, tests, performance issues and deficiencies and issue resolutions, and
- Documentation of installed/constructed equipment and assembly specifications
- A clear methodology to evaluate building performance against that standard to achieved a final acceptance of the Project (Re-Commissioning Plan).

4. Effectively Transfer Knowledge to the Building Operations Team

In order for the commissioning process to deliver sustainable results, the operations team responsible for the facility must be adequately prepared to assume responsibility for the installed equipment and systems at Final Acceptance of the project. It is the primary responsibility of the Commissioning Team to manage the training process to effectively prepare this team to understand and properly operate the high performance systems that will be required to sustain the mission. To this end, the Commissioning team should:

- Engage the Operations Team in the Commissioning Process as early as possible:
- Organize and prepare all Contractors and Vendors to deliver coherent training to the Operations Team;
- Provide Systems Training and Key Performance Criteria to guide operators in monitoring and evaluating their operating systems; and
- Provide Training, O&M, Performance and Re-Commissioning Documentation that will allow a facility to maintain a knowledgeable and effective operations team for the life of the facility (Sebesta Blomberg and Associates, July 9, 2010).

2.2.2. ASHRAE Guideline 0-2005 and Total Building Commissioning

To standardize the practice of Building Commissioning, ASHRAE introduced the first Guideline (later named Guideline 1) for commissioning HVAC systems in 1989. Later on, in response to growing demand for implementing Total Building Commissioning in construction projects, the National Institute of Building Sciences (NIBS) collaborated with ASHRAE to develop a comprehensive commissioning

Guideline called *Guideline 0-2005*. Guideline 0-2005 is a document that defines the process of Building Commissioning, apart from its application to specific building systems. In other words, Guideline 0-2005 defines basic procedures and activities that are common in the commissioning of all different building systems, and also serves as a framework for the Owner's Project Requirements (OPR).

In practice, Guideline 0-2005 is used in conjunction with system-specific Guidelines to commission one or more building systems. Working groups within various professional organizations are in charge of developing system-specific Guidelines (Shakoorian, 2006). (For Guidelines and their current stage and the responsible organization, see Appendix C.)

Commissioning Team and Commissioning Authority

Guideline 0-2005 defines commissioning as a group effort. Commissioning activities are carried out by the *Commissioning Team*, a group of "*individuals who through coordinated activities are responsible for implementing the commissioning process."* Commissioning Team members include: *Owner representatives, Commissioning Authority, Pre-design and Programming Professionals, Design Professionals* and *Construction Professionals*.

This Guideline defines *Commissioning Authority* as an entity that *"leads, plans, schedules, and coordinates the commissioning team to implement the commissioning process."* In other words, the Commissioning Authority (CA) is the entity responsible for the Commissioning Process. For an entity to be a Commissioning Authority, it must have extensive knowledge and experience with different building systems and their interactions. In addition to this expertise, other general qualifications, such as communication skills, management expertise and administrative proficiency, have been identified as essential (Dunn, 1994). Guideline 0-2005 elaborately defines the roles and responsibilities for the Commissioning Authority. A list of these responsibilities is provided in Table 2.1.

Table 2.1 - Responsibilities of the Commissioning Authority based on Guideline 0-2005 (ASHRAE, Guideline 0-2005)

1	Organize and lead the Commissioning Team
2	Facilitate and Document the Owner's Project Requirements
3	Verify that the Commissioning Process activities are clearly stated in all scopes of work
4	Integrate the Commissioning Process activities into the project schedule
5	Prepare a Commissioning Plan that describes the extent of the Commissioning Process to accomplish the Owner's Project Requirements. Update the Commissioning Plan during each phase of the project to incorporate changes and additional information.
6	Review and Comment on the ability of the design documents to achieve the Owner's Project Requirements for the commissioned systems and assemblies.
7	Prepare the Commissioning Process activities to be included as part of the project specifications. Include a list of all individual trade contractor responsibilities for all the Commissioning Process activities.
8	Execute the Commissioning Process through the writing and review of Commissioning Process Reports, organization of all Commissioning Team

Table 2.1 continued

	meetings, tests, demonstrations, and training events described in the Contract Documents and approved Commissioning Plan. Organizational responsibilities include preparation of agendas, attendance lists, and arrangements for facilities, and timely notification to participants for each Commissioning Process activity. The Commissioning Authority shall act as chair at all commissioning events and ensure execution of all agenda items. The Commissioning Authority shall prepare minutes of every Commissioning Process activity and send copies to all Commissioning Team members and attendees within five workdays of the event.
9	Review the plans and specifications (during Pre-Design and Design Phases) with respect to their completeness in all areas relating to the Commissioning Process. This includes verifying that the Owner's Project Requirements have been achieved, and that there are adequate devices included in the design to properly test the systems and assemblies and to document the performance of each piece of equipment, system, or assembly.
10	Schedule all document review coordination meetings.
11	Attend the project's pre-bid meeting to detail the design professional or contractor Commissioning Process requirements.
12	Schedule the pre-design and pre-construction Commissioning Process meeting within 60 days of the award of the contract at some convenient location and at a time suitable to the attendees. This meeting will be for the purpose of reviewing the complete Commissioning Process and establishing a tentative schedule for the Design Phase and Construction Phase

Table 2.1 continued

	commissioning activities.
13	Develop the initial format to be used for Issues Logs throughout and for each phase of the Commissioning Process.
14	Schedule the initial Owner training session so that it will be held immediately before the contractor training. This session will be attended by the Owner's O&M personnel, the design professionals, the contractor, and the Commissioning Authority. The Commissioning Authority will review the Owner's Project Requirements and the design professional will review the Basis of Design.
15	Review proposed contractor-provided training program to verify that the Owner's Project Requirements (OPR) are achieved.
16	Attend a portion of the contractor-provided training sessions to verify that the Owner's Project Requirements are achieved.
17	Receive and review the Systems Manual as submitted by the contractor. Verify that it achieves the Owner's Project Requirements. Insert systems descriptions as provided by the design professional in the System Manual.
18	Witness system and assembly testing. Verify the results and include a summary of deficiencies.
19	Supervise the Commissioning Team members in completion of tests. The test data will be part of the Commissioning Process Report.
20	Periodically review Record Drawings for accuracy with respect to the installed systems and request revisions to achieve accuracy.
21	Verify that the systems Manual and all other design and construction records have been updated to include all modifications made during the Construction Phase.
22	Repeat implementing of tests to accommodate seasonal tests or to correct

Table 2.1 continued

	any performance deficiencies. Revise and resubmit the Commissioning Process Report.
23	Prepare the final Commissioning Process Report.
24	Assemble the final documentation, which includes the Commissioning Process Report, the Systems Manual, and all record documents. Submit this documentation to the Owner for review and acceptance.
25	Recommend acceptance of the individual systems and assemblies to the Owner (in accordance with the defined project requirements).

2.3. Process Performance

In this research, the outcome of the commissioning process is defined in terms of performance measures. Therefore, this section provides an overview of the concept of performance measurement, as it relates to different processes. The goal is to explore the evolution of performance measurement and identify state-of-the-art research, in order to provide a basis for developing performance measures for the commissioning process. The literature identified for this review was obtained through a search of peer-reviewed journals in several fields of study, including Strategic Planning, Process Management, Program Management and Construction Management

Definition

Performance measurement is a broadly defined concept. Neely (Neely A. G., 1995) defines performance measurement as *"the process of quantifying the efficiency and effectiveness of actions."* Evangelidis (Evangelidis, 1992) uses a more goal-oriented approach and defines performance measurement as the process of "*determining how successful organizations or individuals have been in attaining their objectives."* Atkinson (Atkinson A. A., 1997 August/September) also discusses the importance of linking the performance measurement to strategic planning, and defines performance measurement as a tool for monitoring the activities undertaken towards defined strategic goals.

Although each of these definitions focuses on a certain aspect of performance, they all point to the main characteristic of performance measurement, which can be defined as a process for measuring an object/action's ability to achieve a pre-defined goal. In this sense, performance measurement can be both a *lagging* and a *leading* activity. In other words, this process can be used to measure the realized capacity of an action of the past, in relation to an achieved goal, or it can be used to measure the potential of an action to render a defined-but-unachieved goal in the future.

Evolution of Performance Measurement Frameworks

The use of performance measurement can be traced back to the 1860s and 1870s when the U.S. railroads started to use planning and control procedures to manage their contracts (Chandler, 1977) (Kaplan R. S., 1984). In the early 1900s, the DuPont Company introduced the *Return on Investment* (ROI) as the first financial performance measure. Since the introduction of ROI, other financial measures such as *Discounted Cash Flow*, *Residual Income, Economic Value Added* and *Cash Flow Return on Investment* have been introduced (Bassioni, April 2004,). Financial performance measures have been widely used in different industries, due to the fact that they can easily be incorporated into companies' accounting practices. At the same time, the use of financial measures has not been free of criticism. The major criticism towards their use is based on the fact that these are "lagging metrics," in that they measure the past and, therefore, cannot be used for improvements (Ghalayini, 1996). In addition, critics argue that financial performance measures do not provide decision-makers with information required to manage and improve existing processes (Atkinson A. A., 1997

August/September). Neely et al. (Neely A. R., 1997) identified additional reasons for criticism of financial measures. These criticisms are:

- Encourage "short-termism" and lack strategic focus;
- Failure to provide data on important aspects, such as quality, responsiveness and flexibility; and,
- Encourage local optimization and do not encourage continuous improvement.
- In response to the inadequacy of these traditional measures, new performance measurement frameworks have been proposed in recent years.

Maskell (Maskell, 1989) proposed a set of performance measures based on world-class manufacturing elements, such as *quality*, *time*, *process* and *flexibility*. Cross and Lynch (Cross, 1988) proposed the use of different performance measures at differing levels of the company, in the form of the *Performance Pyramid* (Figure 2.1). Finally, an important performance measurement system is Kaplan and Norton's (Kaplan R. S., 1992) *Balance Scorecard*. This framework defines four broad perspectives for performance measurement: *financial*, *customer*, *internal processes and innovation*. Balance Scorecard has gained a lot of attention in both industry and academia, and has been used as the basis for many other performance frameworks. A comprehensive review of Balance Scorecard, and other contemporary performance measurement frameworks, is provided in (Bassioni, April 2004,) ; (Kagioglou, 2001).

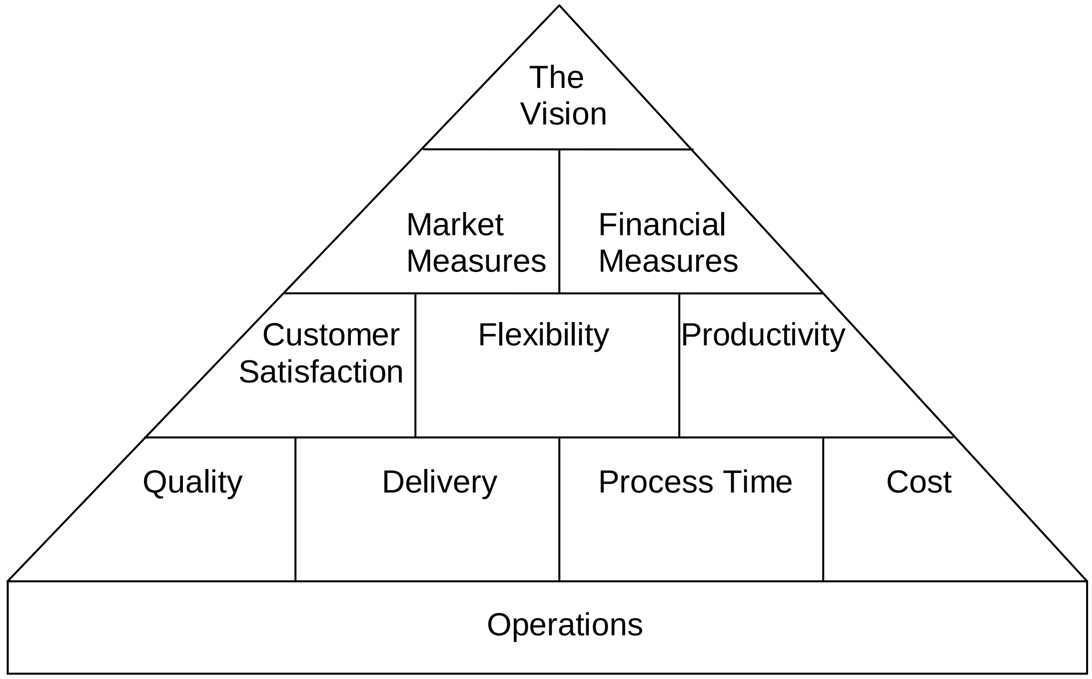


Figure 2.1 Performance Pyramid (Cross, 1988)

Performance Measurement in Construction

Performance measurement in the construction industry has taken two different approaches (Kagioglou, 2001). The first measurement is in relation to the created product as the facility. The second measurement relates to the creation of the product as the process. Performance of construction products and facilities has been a major source of discussion in both academia and industry and has its own rich literature. However, as the focus of this study is to develop performance measures for the commissioning process, this section only concentrates on the performance of the process.

Traditionally, the construction industry has relied on financial measures, such as *return on capital* and *profitability,* in a performance evaluation of construction organizations (Bassioni, April 2004,). However, recently the need for a more long-term and broader focus on corporate strategy, business process and stakeholders has been recognized (Love, 2000). At the same time, the construction industry is a project-oriented industry (Wegelius-Lehtonen, 2001). Therefore, most of the efforts in developing performance measurement frameworks in the construction industry have focused on the performance of the projects (Love, 2000).

Munns and Bjerimi (Munns, 1996) define *project* as achievement of a specified objective, which involves a series of activities and tasks that consume resources. Therefore, the major performance goal of a project is *success* (Chan A. P., 2004). At the project level, success has been measured by the *project duration*, *monetary cost* and *project performance* (Navarre, 1990). These three aspects of *time*, *cost* and *quality* have been widely used as the major performance indicators for construction projects (Bassioni, April 2004,); (Chan A. P., 2004); (Kagioglou, 2001); (Mohsini, 1992); (Ward, 1991).

However, use of these indicators has not been without criticism. Kagioglou et al. (Kagioglou, 2001) argue that these measures by themselves don't provide a balanced view of the project's success. They also mention that these indicators are lagging measures, which focus on the outcomes of the project and, therefore, do not provide any planning value.

Nahapiet and Nahapiet's (Nahapiet, 1985) research shows no clear relationship between satisfaction expressed by clients and project performance in absolute terms, such as *cost per unit of floor area*, or *floor area constructed per unit of time*. Ward et al. (Ward, 1991) further suggest that these three measures (cost, time, quality) are inter-related and, in most cases, incompatible in nature. In other words, achieving a high performance in one dimension will reduce the performance in another dimension. They also argue that the overall performance of the project goes back to the Owners' memory of the project, which is mostly affected by the quality of relationships in the project. In response to these critiques, new measures of performance have been proposed in construction management literature.

Chan and Chan (Chan A. P., 2004) provide a comprehensive overview of the evolution of performance measures during the 1990s.

These include: "psychosocial outcomes" by Pinto and Pinto (Pinto, 1991); "satisfaction" by Wuellner (Wuellner, 1990); "conflict-inducing variables" by Mohsini and Davidson (Mohsini, 1992); "maintenance cost" and "flexibility" by Kometa et al. (Kometa, 1995); "conformance to user expectations", "meeting specifications", "quality workmanship", and "minimizing construction aggravation" by Songer and Molennar (Songer, 1997); and "transfer of technology", "friendliness of environment" and "health and safety" by Kumaraswamy and Thorpe (Kumaraswamy M. M., 1996).

In addition, other frameworks have been proposed that use a more comprehensive approach. Shenhar et al. (Shenhar, 1997) suggest a framework that presents these four performance categories: *Project Efficiency*, *Impact on Customer*, *Business Success*, and Preparing *for the Future* (Figure 2.2). Atkinson (Atkinson R. , 1999) uses a different approach, and defines the project success in the three stages of a project life-cycle (Figure 2.3). Lim and Mohamed (Lim, 1999) argue that project performance should be viewed at micro and macro levels (Figure 2.4). At the micro level, they suggest use of performance-measures that focus on the project itself. The macro level, on the other hand, is compromised of performance measures that focus on the whole life-cycle of the facility. Sadeh et al. (Sadeh, 2000) divide project success into four dimensions: *Meeting design goals; Benefit to the end user; Benefit to the developing organization;* and *Benefit to the technological infrastructure of the country and of firms involved in the development process.*

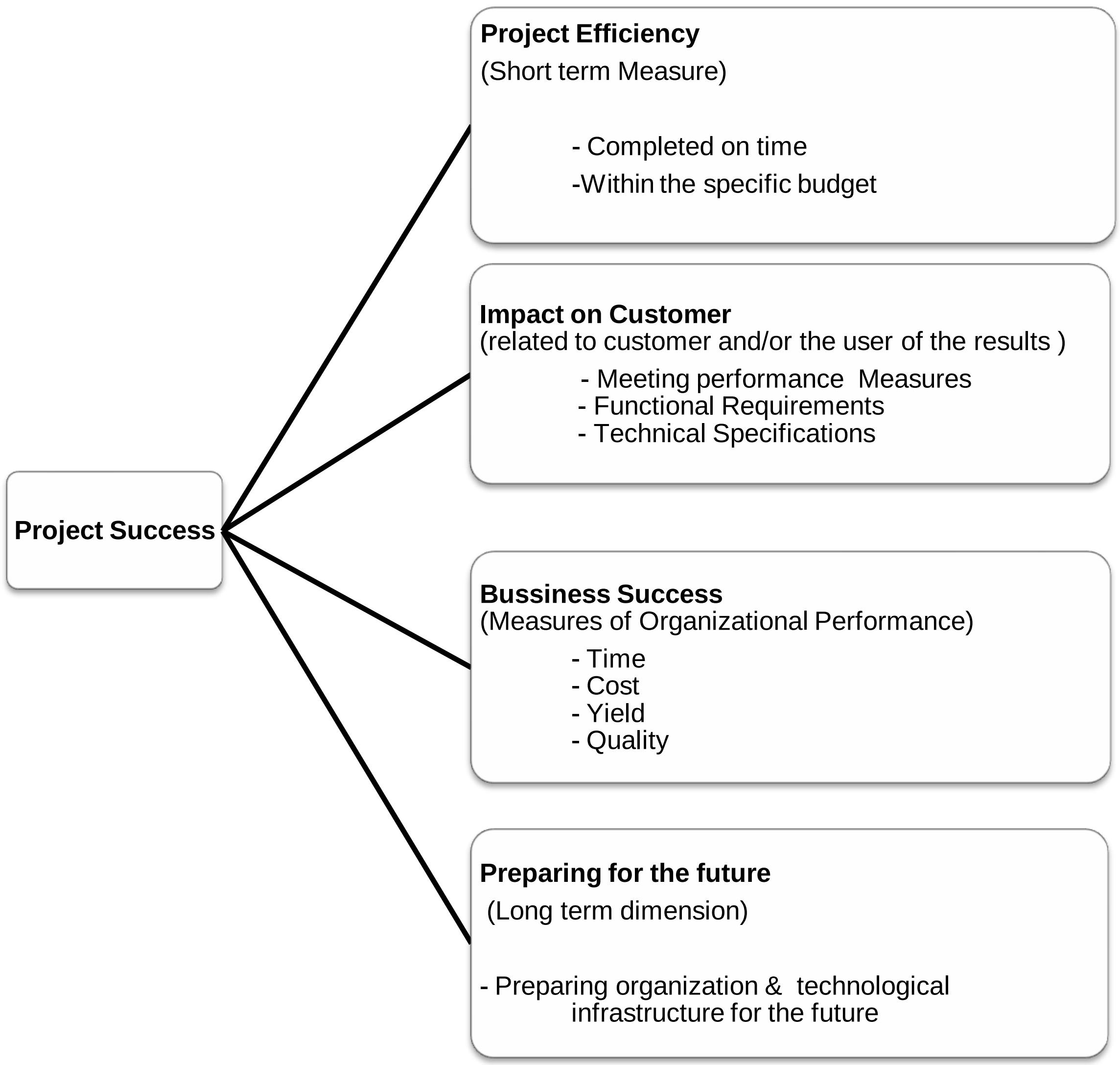


Figure 2.2 Performance Framework by Shenhar (1997)

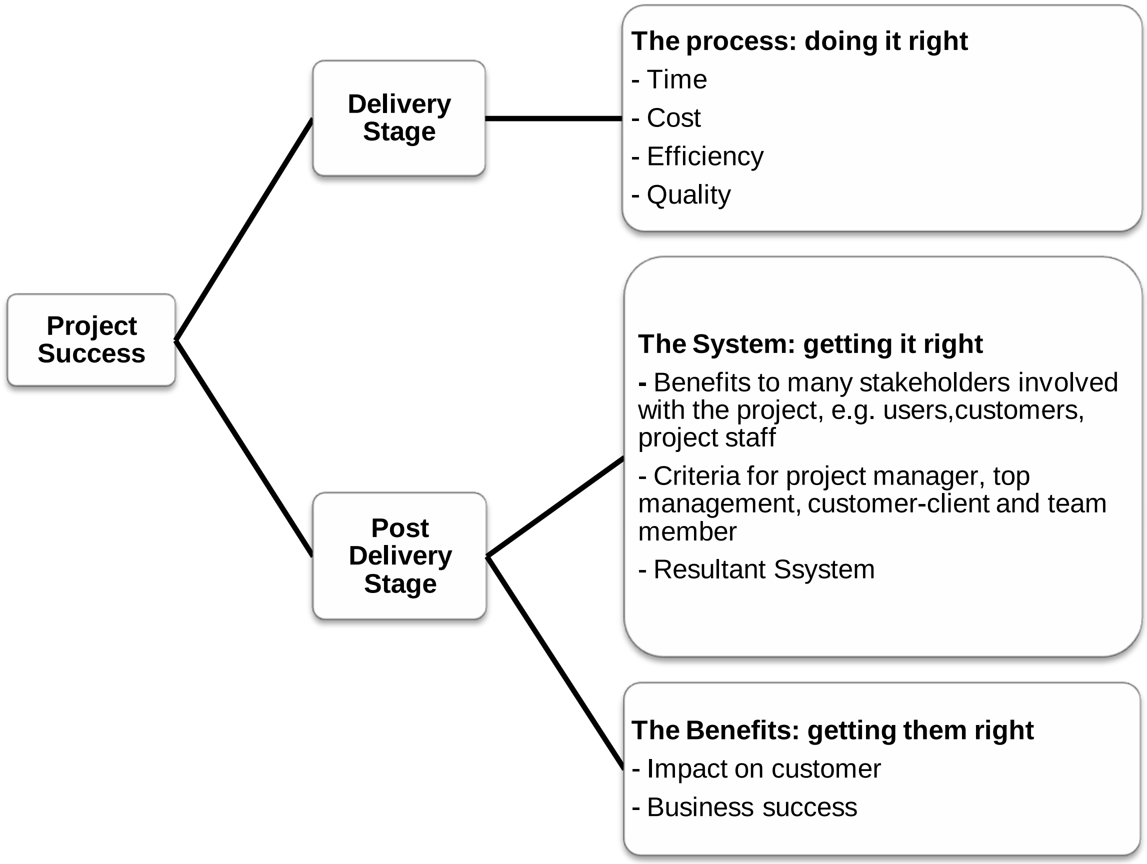


Figure 2.3 Performance Framework by Atkinson (1999)

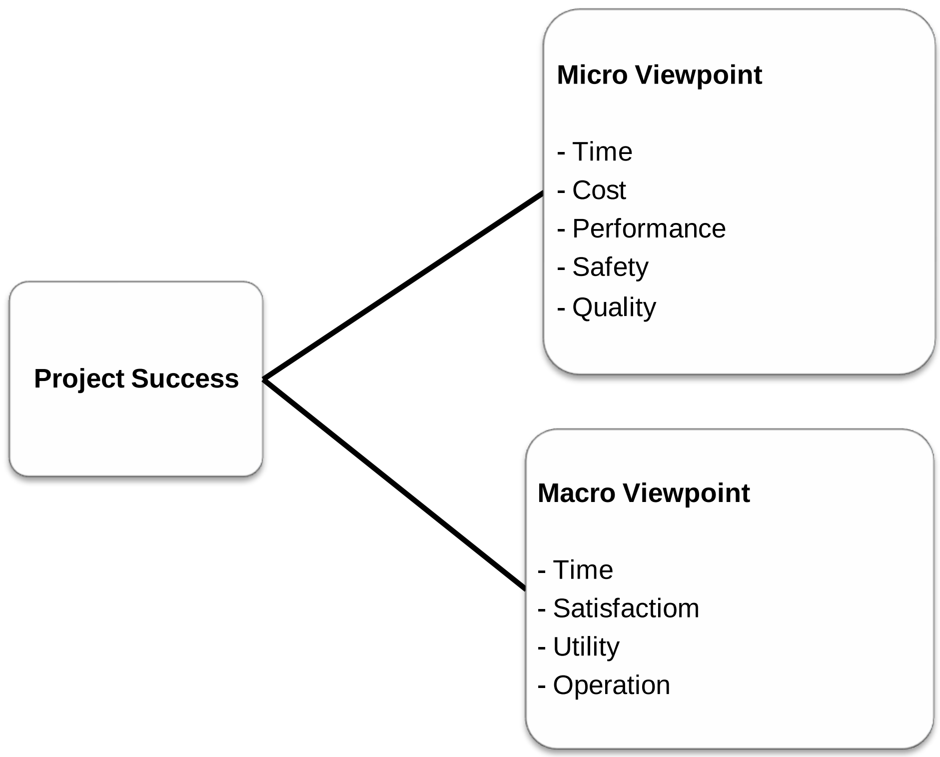


Figure 2.4 Performance Framework by Lim and Mohamed (1999)

Another performance framework is Key Performance Indicators (KPI), launched by the United Kingdom's Construction Best Practices Program (CBPP). The purpose of KPI is to enable the measurement of the project and organizational performance in the construction industry (The_KPI_Working_Group., 2000). Table 2.2 shows the project and company indicators that KPI proposes. A comprehensive review of KPI is provided in Chan and Chan (Chan A. P., 2004) and Bassioni et al. (Bassioni, April 2004,).

Table 2.2 Key Performance Indicators for Construction Firms (KPI 2000)

Project Performance	**Company Performance**
Construction Cost	Safety
Construction Time	Profitability
Predictability – Cost	Productivity
Predictability – Time	
Defects	
Client satisfaction - Product	
Client satisfaction - Service	

Internal Performance Aspects

Most of the performance measures and frameworks that were described previously focus on the overall outcome of the project as the basis for measuring the project performance. Therefore, we call them *External Performance Aspects*. At the same time, a different approach towards performance measurement has been based on the project itself. In this approach, the focus is on characteristics of the internal processes of a project, and the internal mechanics and interactions between different entities in that project. We call these performance measures *Internal Performance Aspects*.

One of the most useful models in explaining the relationship between external and internal aspects has been suggested by Brawn (Brawn, 1996) as shown in Figure 2.2, this framework makes a distinction between different measures used for stages of *Inputs*, *Processes*, *Outputs* and *Outcomes*. By using the analogy of baking a cake, Brawn explains the process (internal) measures can be defined as *speed of the mixer, length of time the batter/dough is mixed,* and *temperature of the oven*, as opposed to outcome (external) measures which can be the *color* and *taste* of the cake.

Brawn supports the use of process measures, as they will guarantee achievement of good outcomes through improving the processes. At the same time, he agrees that process measures should be selected based on their correlation to the performance of the outcome (Brawn, 1996).

In the construction industry, internal aspects are not as widely used as external measures; however, there are some studies that support this approach of performance measurement. Pocock et al. (Pocock J. B., 1996b) (Pocock J. B., 1997) propose the use of performance measures, such as *safety* and *degree of interaction*. In his study, Walker (Walker, 1995) shows the importance of *communication* and the *quality of relationships* among different stakeholders on the construction time performance. Kumaraswamy and Dissannayaka (Kumaraswamy M. M., 1998) use internal factors of *effective and efficient communication* and *effective and efficient decision-making* as the relevant performance criteria for procurement selection. Ward et al. (Ward, 1991) argue that the best way to compare different project alternatives is to focus on the project itself. They propose a more-comprehensive framework that presents seven internal performance aspects of *adaptation, allocation, coordination, integration, tension management, productivity,* and *integrity*.

2.4. Summary of Literature Review

The first section of this chapter provided an overview of the practice of Building Commissioning and the evolution of this concept over the past 30 years. This review shows how this practice has emerged to a quality assurance tool. Different types of Building Commissioning are presented, and Total Building Commissioning is introduced as the main focus of this study. Also, ASHRAE Guideline 0-2005, the major source for defining the process of Total Building Commissioning, is described.

The second section of this chapter provides an overview of the existing literature on performance measurement as it relates to processes. The objective is to identify state-of-the-art performance research, and to establish a point of departure for utilization of performance measurement in this research.

Different definitions of performance were provided and, as a result, this concept was described as a process of measuring an object/action's ability to achieve a predefined goal. A brief overview of the evolution of the concept of performance measurement was provided and major performance frameworks across industries were reviewed. This chapter also provided an overview of the application of performance measurement in the construction industry, along with major performance frameworks proposed in this industry. The application of internal performance measures, which focus on the process rather than the overall project outcome, was also discussed. The next chapter describes the methodology used in this research.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Purpose

The previous chapter provided an overview of existing literature on the subjects of Building Commissioning and the Construction Administration phase of construction. This chapter describes the research methodology used in this dissertation. First, different methods of research will be described. The use of each methodology will be explained in detail and how they may be applied to this dissertation.

3.2 Research Methodologies

Based on current academic research literature in Integrated Project Delivery (IPD), the most common and major methodologies used in IPD are qualitative research methods and quantitative research methods. There are other research methods used by researchers in this field, such as descriptive, applied, exploratory and basic. In simple terms, we can think of two approaches to investigations in educational research: qualitative and quantitative. In the former, we use words to describe the outcomes and in the latter we use numbers (Berry, 2006).

3.2.1 Qualitative research

Qualitative research is characterized by an emphasis on describing, understanding, and explaining complex phenomena. An example is the relationships, patterns and configurations among factors, or the context in which the activities occur. The focus is on understanding the full multi-dimensional, dynamic picture of the subject of study.

The qualitative approach is considered a contrast from quantitative methods that aim to divide phenomena into manageable, clearly defined pieces, or variables. Quantification is useful for separating phenomena into distinct and workable elements of a well-defined conceptual framework. However, when the focus is on subjects that can be reliably quantified, we may miss factors that are significant to a real understanding of the phenomena being studied. The downside of quantification is that it does not always support understanding of complex, dynamic and multi-dimensional wholes as well as qualitative methods are able to do.

Qualitative methods are useful, not only in providing rich descriptions of complex phenomena, but in constructing or developing theories or conceptual frameworks, and in generating hypotheses to explain those phenomena (Department of Veterans affair 2010). Qualitative research methodology explores attitudes, behavior and experiences through methods such as interviews or focus groups. It attempts to get an in-depth opinion from participants. Generally, fewer people take part in the research, but the contact with these participants tends to last a lot longer. Under the umbrella of qualitative research many different methodologies are used. These methods may include surveys, laboratory experiments and formal methods such as econometrics numerical methods using a mathematical modeling.

Qualitative research methods were developed in the social sciences to enable researchers to study social and cultural phenomenon. Examples of qualitative methods include:

- Action research aimed to contribute both to the practical concerns of people in an immediate problematic situation and to the goals of social science by joint collaboration within a mutually acceptable ethical framework;

- Case study research is an empirical enquiry that investigates a contemporary phenomenon within its real-life context;
- Ethnography involves researcher immersion in the life of people she/he studies and seeks to place the phenomena studied in its social and cultural context.

Data can be collected through a number of different means. A researcher can use a questionnaire, or choose to measure just two or several variables by observation or testing. The variables we are interested in may be dependent or independent. There will be other features present in the problem that may be constant or confounding. Using the data that you have collected, you can describe the variables, in terms of distribution, frequency, central tendency and measures and form of dispersion. The researcher can also infer significant, generalized relationships between variables. The tests employed are designed to find out whether your data is due to chance or because something interesting is going on (Berry, 2006).

Common steps of Qualitative Methods*:*

Steps that are taken using qualitative research methodology are:

Observations

Observational techniques are methods by which an individual or individuals gather first hand data on programs, processes, or behaviors being studied. Researchers are able to collect data on a wide range of behaviors, capture a great variety of interactions, and openly explore the evaluation topic. By directly observing operations and activities, the researcher can develop a holistic perspective, i.e., an understanding of the context within which the project operates. This may be especially important where it is not the event that is of interest, but rather how that event may fit into, or be impacted by, a sequence of events. Observational approaches also allow the researcher to learn about things of which the participants or staff may be unaware, or that they are unwilling or unable to discuss in an interview or focus group (Frechtling j., 1997).

Interviews

Interviews provide very different data from observations: they allow the researcher or research team to capture the perspectives of project participants, staff, and others associated with the project. The use of interviews as a data collection method begins with the assumption that the participants' perspectives are meaningful, and knowledgeable. The participants should be able to add explicit comments about how their perspectives would affect the success of the project. An interview, rather than a paper and pencil survey, is selected when interpersonal contact is important and when opportunities for following up on interesting comments is desired.

Two types of interviews are used in evaluation research. The first is a structured interview, in which a carefully worded questionnaire is administered. The second is an in-depth interview, in which the interviewer does not follow a rigid form. In the former, the emphasis is on obtaining answers to carefully phrased questions, and interviewers are trained to deviate only minimally from the question wording to ensure uniformity of interview administration. In the latter, the interviewers seek to encourage free and open responses, and there may be a trade-off between comprehensive coverage of topics and in-depth exploration of a more limited set of questions. In-depth interviews also encourage capturing of respondents' perceptions in their own words, a desirable strategy in qualitative data collection. This allows the evaluator to present the meaningfulness of the experience from the respondent's perspective. In-depth interviews are conducted with one individual or with a small group of individuals[1] (Frechtling j., 1997).

In-depth Interviews

An in-depth interview is a dialogue between a skilled interviewer and an interviewee. Its goal is to elicit rich, detailed material that can be used in analysis (Lofland, 1995). Such interviews are best conducted face-to-face, although in some situations telephone interviewing can be successful.

In-depth interviews are characterized by extensive probing and open-ended questions. Typically, the project evaluator prepares an interview guide that includes a list of questions or issues that are to be explored and suggested probes for following up on key topics. The guide helps the interviewer pace the interview and makes interviewing more systematic and comprehensive. Lofland and Lofland (Lofland, 1995) provide Guidelines for preparing interview guides, doing the interview with the guide, and documenting the interview. The dynamics of interviewing are similar to a guided conversation. The interviewer becomes an attentive listener who shapes the process into a familiar and comfortable form of social engagement - a conversation - and the quality of the information obtained is largely dependent on the interviewer's skills and

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[1] A special case of the group interview is called a focus group. Although we discuss focus groups separately, several of the exhibits in this section will refer to both forms of data collection because of their similarities.

personality (Patton, 1990). In contrast to a good conversation, however, an in-depth interview is not intended to be a two-way form of communication and sharing.

The key to being a good interviewer is being a good listener and questioner. The interviewer should not put forth his or her opinions, perceptions, or feelings. Interviewers should be trained individuals who are sensitive, empathetic, and able to establish a non-threatening environment in which participants feel comfortable. They should be selected during a process that weighs personal characteristics that will make them acceptable to the individuals being interviewed. Certainly, age, sex, profession, race/ethnicity and appearance may be key characteristics. Thorough training, including familiarization with the project and its goals, is important. Poor interviewing skills, poor phrasing of questions, or inadequate knowledge of the subject's culture or frame of reference may result in a collection that obtains little useful data (Frechtling j., 1997).

Recording Interview Data

Interview data can be recorded on tape, with the permission of the participants, and/or summarized in notes. As with observations, detailed recording is a necessary component of interviews since it forms the basis for analyzing the data. All methods, but especially the second and third, require carefully crafted interview guides for recording the interviewee's responses. Three procedures for recording the data are presented below.

In the first approach, the interviewer (or in some cases the transcriber) listens to the tapes and writes a verbatim account of everything that was said. Transcription of the raw data includes word-for-word quotations of the participant's responses, as well as the interviewer's descriptions of participant's characteristics, enthusiasm, body language, and overall mood during the interview. Notes from the interview can be used to identify speakers or to recall comments that are garbled or unclear on the tape. This approach is recommended when the necessary financial and human resources are available, when the transcriptions can be produced in a reasonable amount of time, when the focus of the interview is to make detailed comparisons, or when respondents' own words and phrasing are needed. The major advantages of this transcription method are its completeness and the opportunity it affords for the interviewer to remain attentive and focused during the interview. The major disadvantages are the amount of time and resources needed to produce complete transcriptions and the inhibitory impact tape recording has on some respondents. If this technique is selected, it is essential that the participants have been informed that their answers are being recorded, that they are assured confidentiality, and that their permission has been obtained.

A second possible procedure for recording interviews draws less on the word-by-word recording and more on the notes taken by the interviewer or assigned note-taker. This method is called "note expansion." As soon as possible after the interview concludes, the interviewer listens to the tape to clarify certain issues and to confirm that all the main points have been included in the notes. This approach is recommended when resources are scarce, when the results must be produced in a short period of time, and when the purpose of the interview is to get rapid feedback from members of the target population. The note expansion approach saves time and retains all the essential points of the discussion. While this approach has benefits, a disadvantage is that the interviewer may be more selective or biased in what he or she writes.

In the third approach, the interviewer uses no tape recording, but instead takes detailed notes during the interview and draws on memory to expand and clarify the notes immediately after the interview. This approach is useful if time is short, the results are needed quickly, and the evaluation questions are simple. Where more-complex questions are involved, effective note-taking can be achieved, but only after much practice. Further, the interviewer must frequently talk and write at the same time, a skill that is hard for some to achieve (Frechtling j., 1997).

Focus Groups

Focus groups combine elements of both interviewing and participant observation. The focus group session is, indeed, an interview (Patton, 1990) not a discussion group, problem-solving session, or decision-making group. At the same time, focus groups capitalize on group dynamics. The hallmark of focus groups is the explicit use of the group interaction to generate data and insights that would be unlikely to emerge without the interaction found in a group. The technique inherently allows observation of group dynamics, discussion, and firsthand insights into the respondents' behaviors, attitudes, language, etc.

Focus groups are a gathering of 8 to 12 people who share some characteristics relevant to the evaluation. Originally used as a market research tool to investigate the appeal of various products, the focus group technique has been adopted by other fields, such as education, as a tool for data gathering on a given topic. Focus groups conducted by experts often take place in a focus group facility that includes recording apparatus (audio and/or visual) and an attached room with a one-way mirror for observation. There is an official recorder who may or may not be in the room. Participants are usually paid for attendance and provided with refreshments. As the focus group technique has been adopted by fields outside of marketing, some of these features, such as payment or refreshment, have been eliminated (Frechtling j., 1997).

Other Qualitative Methods

The last section of this chapter outlines less common but, nonetheless, potentially useful qualitative methods for conducting research. These methods include document studies, key informants, alternative (authentic) assessment, and case studies (Frechtling j., 1997).

Document Studies

Existing records often provide insights into a setting and/or group of people that cannot be observed or noted in another way. This information can be found in document form. Lincoln and Guba (1985) defined a document as "any written or recorded material" not prepared for the purposes of the research or at the request of the inquirer. Documents can be divided into two major categories: public records and personal documents (Guba, 1981).

Public records are materials created and kept for the purpose of "attesting to an event or providing an accounting" (Lincoln, 1985). Public records can be collected from outside (*external*) or within (*internal*) the setting in which the evaluation is taking place. Examples of *external* records are census and vital statistics reports, county office records, newspaper archives and local business records that can assist an evaluator in gathering information about the larger community and relevant trends. Such materials can be helpful in better understanding the project participants and making comparisons between groups/communities (Frechtling j., 1997). For example, for the evaluation of educational innovations, *internal* records include documents, such as student transcripts and records, historical accounts, institutional mission statements, annual reports, budgets, grade and standardized test reports, minutes of meetings, internal memoranda, policy manuals, institutional histories, college/university catalogs, faculty and student handbooks, official correspondence, demographic material, mass media reports and presentations, and descriptions of program development and evaluation. Internal records are particularly useful in describing institutional characteristics, such as backgrounds and academic performance of students, and in identifying institutional strengths and weaknesses. They can help the evaluator understand the institution's resources, values, processes, priorities, and concerns. Furthermore, they provide a record or history not subject to recall bias (Frechtling j., 1997).

Personal documents are first-person accounts of events and experiences. These "documents of life" include diaries, portfolios, photographs, artwork, schedules, scrapbooks, poetry, letters to the paper, etc. Personal documents can help the evaluator understand how the participant sees the world and what she or he wants to communicate to an audience. And, unlike other sources of qualitative data, collecting data from documents is relatively invisible to, and requires minimal cooperation from, persons within the setting being studied (Fetterman, 1989).

The usefulness of existing sources varies depending on whether they are accessible and accurate. Documents can provide the researcher with useful information about the culture of the institution and participants involved in the project, which, in turn, can assist in the development of the researcher questions. Information from documents also can be used to generate interview questions or to identify events to be observed. Furthermore, existing records can be useful for making comparisons (e.g., comparing project participants to project applicants, project proposal to implementation records, or documentation of institutional policies and program descriptions prior to and following implementation of project interventions and activities). (Frechtling j., 1997).

3.2.2 Quantitative Research

Quantitative research methodology often generates statistics through the use of large-scale survey research, using methods such as questionnaires or structured interviews. For example, a market researcher has stopped you on the streets, or you have filled in a questionnaire which has arrived through the post, this falls under the umbrella of quantitative research. This type of research reaches many more people, and generally is much quicker than qualitative research. Quantitative analysis has been one of the most widely-used methodologies in assessing the effect of procurement-related factors on project outcome. However, in response to the inadequacies of the traditional scientific approach in analyzing human systems, construction management research has relied on more qualitative methods of inquiry. One of most common forms of qualitative inquiry is called *Interpretive Approach* (Seymour, 1997).

Interpretive Approach:

Interpretive studies assume that people create and associate their own subjective and inter-subjective meanings as they interact with the world around them. Interpretive researchers thus attempt to understand phenomena through accessing the meanings participants assign to them (Orlikowski, 1991).

Interpretive methods of research start from the position that our knowledge of reality, including the domain of human action, is a social construction by human actors and that this applies equally to researchers. Thus, there is no objective reality which can be discovered by researchers and replicated by others, in contrast to the assumptions of positivist science (Orlikowski, 1991).

The interpretive research approach is based on the idea that the researcher can never assume a value-neutral stance, and is always implicated in the phenomena being studied' 'There is no direct access to reality unmediated by language and preconception (Orlikowski, 1991).

Education research has largely moved away from the numbers approach in recent years, and the emphasis has been on qualitative methods. However, the use of numbers can be useful, either as part of a larger project that employs many different methods or as a basis for a complete piece of work. With the use of sophisticated software packages, such as SPSS, it is relatively easy to compute tables and charts almost instantly once your data is entered into the software program. However, it is very important that the underlying principles of statistical analysis are understood, in order to understand the results that emerge from the software program (Berry, 2006).

3.2.3. Research Methodology

The Owner's Project Requirements are considered the heart and soul of the Commissioning Process. When the Owner's Project Requirements are not developed, the Owner, designer, contractors, and operation and maintenance (O&M) personnel each interpret the building requirements, including their individual responsibilities, from the standpoint of their own specific needs. This often creates a range of diverse views of the constructed project's needs. Unfortunately, while critical for a successful project, the Owner's Project Requirements are rarely developed. Developing Owner's Project Requirements that reflect the actual needs of the Owner, the users or occupants, service and operating units, and sometimes the community is one of the, if not the, most important aspects for successful implementation of the Commissioning Process (Guideline 0-2005, 2005).

This research proposes a methodology in which the qualitative approach of the interpretive analysis is used. The aim of Interpretive Approach in this study is to define a systematic process, through which explicit and tacit knowledge of experts about the construction process of structural system, with the evaluation of construction administration documents, is obtained based on established criteria.

The collective knowledge of experts and construction administration documents is then analyzed to identify certain construction/design issues that have the most affect on the outcome of a construction project and provide a basis for comparison. The purpose of these analyses is to provide an evaluation of these construction/design issues and also investigate the issues and problems, which have led to construction/design issues in the field. The results of these investigations can be used by the Owners to identify the areas of concern and current problems in the construction process, and provide a roadmap for further investigation and improvement of these issues. This study is comprised of seven distinct phases:

- Phase 1: Investigating the issues that were raised during construction observation, investigation of the construction administration documents of a project and identification of important issues impacting structural performance.
- Phase 2: Interviewing experts to explore issues that arose in the construction process or were dictated by market demands.
- Phase 3: Confirm construction/design issues gathered in #1 and #2 with the knowledge of experts.
- Phase 4: Document review to establish an initial Owners Project Requirement for the Structural System.

- Phase 5: Performance assessment and classification of construction/design issues.
- Phase 6: Develop suggested Owners Project Requirement for the Total Structural Systems (OPRTSS). Framework for the Owner's Project Requirements (OPR) for the Total Structural Systems (OPRTSS) for structural commissioning of multi-story concrete and steel frame structures to: (1) assist owners and commissioning provider to identify and establish a proper task outline for the structural system, (2) identify Structural Engineers responsibilities and expected performance, and (3) guide structural Engineer's design teams to the owner's desired final product
- Phase 7: Validation and verification of the suggested OPRTSS with the knowledge of experts for the final OPRTSS.

As this study takes an interpretive approach, a high degree of precision must be applied in performing each of these steps. Therefore, each step of the study is precisely defined and activities are described in detail. These descriptions are provided in the following sections.

3.3 Summary

To establish the framework, ASHRAE Guideline 0-2005, NIBS Guideline 3-2006, and ASHRAE Guideline 1-2007 were reviewed to identify the critical issues involved for creation and development of the initial OPR. In order to complete the OPR for all construction/design issues impacting structural performance, practitioners were interviewed; documents in six Structural Engineering firms were investigated and documented. A review of past and current litigation for structural issues in the construction process of seven projects was conducted. Research involving two law firms was also conducted. These investigations and interviews identified the construction/design issues impacting structural performance in the construction industry. Each of these construction/design issues is described in detail in the next chapter. A checklist of recommended solutions for preventing these issues follows the variable description.

CHAPTER 4

RESEARCH FINDINGS

4.1 Purpose

This chapter is aimed at gathering additional items that are impacting the structural performance of a project, which are not included in the recommendations of Guideline 0-2005. For this purpose, six structural firms were visited and 12 Professional Engineers were interviewed for their view of problems they were facing during a construction process of the structural system. In addition, four General Contractors and Owner Representatives, two Registered Architects and two Attorneys were interviewed for their expertise and experience in the construction field. These construction/design issues are gathered and are listed in this chapter.

4.2. Expert Knowledge Gathering Methodology

This investigation used the expert judgments of those listed above in order to assess the performance of OPRTSS. The aim was to initiate a structured discussion among experts about advantages and disadvantages of each section of the OPRTSS. In order to identify the most appropriate technique for this investigation, a comprehensive study of expert knowledge gathering techniques was performed. The findings of this study are presented in Appendix A of this dissertation. As a result, the Delphi method (Delbecq, 1975) was identified as the most appropriate technique for this study. This technique was chosen due to its ability to provide an environment of discussion among a panel of experts and gain a level of consensus among them, while minimizing the difficulties and negative impacts involved with face-to-face meetings.

Delphi is a structured process which utilizes a series of questionnaires or rounds to gather and provide information (Keeney, 2001). In a Delphi study, the participants are asked individually, via a questionnaire, to provide their estimates for a variable in question. Feedback is then collected and summarized in a way to conceal the origin of original estimates. The results are circulated, and participants are asked if they wish to refine their previous answers based on the summary results.

4.3. The Delphi Technique

The Delphi technique in this research is compromised of three questionnaires. The first Questionnaire is aimed at validating construction/design issues, identified in the previous chapter. The second Questionnaire asks experts to provide an assessment of each section of the OPRTSS. Experts' ratings and comments resulting from the second survey are then summarized and reported back to experts. In the third Questionnaire and experts are asked to validate the accuracy of the OPRTSS.

A statistical measure is calculated for the overall assessments in order to measure the degree of agreement among experts. In cases, where experts reach a consensus of agreement the result is used to identify sections as required sections in the OPRTSS. Where experts did not reach an agreement on the performance ratings, the result is used to identify those sections as not required for the OPRTSS or sections that are case specific.

4.3.1. Expert Selection:

Careful selection of panel members plays a major role in the success of a Delphi Study (Chan A. P., 2001). Therefore, a *purposive* sampling methodology was used.

Experts for this study were defined as individuals who have extensive back ground in the field of Structural Engineering and posses a professional engineering license. Experts were identified and selected using five step methodology, as proposed by Okoli and Pawlowski (Okoli, 2004)[2]. Each of these steps is described below:

Step - 1. Prepare a Knowledge Resource Nomination Worksheet (KRNW). Based on the proposed procedure, the first step is to prepare a KRNW to identify the relevant discipline and structural engineers practicing in the proper field related to the scope of the research.

Step - 2. Populate the KRNW with names. The next step was to prepare a preliminary list of possible candidates. The preliminary list was prepared by identifying the individuals who had extensive experience in the design of structures related to the scope of this research.

Step - 3. Nominate additional experts. The candidates were first contacted by phone. They were given a very brief description of the study and were asked to give the names of other individuals who could be good candidates for the study. The objective was to identify the most qualified individuals.

Step - 4. Rank the Experts. Candidates were categorized according to their expertise. Each candidate was interviewed in person or on the phone. In these interviews, candidates were provided with a more-detailed description of the research. These interviews provided a basis for ranking the candidates. A total of 22 experts were interviewed and ranked during this process.

Step - 5. Invite the Experts. The experts were invited to participate in the study by reviewing the suggested OPRTSS and evaluating each section of the OPRTSS. The result of a literature review on Delphi technique revealed that the maximum validity of a

Delphi study is reached with 8-12 panelists (Hogarth, 1978). A panel size of 42 experts was chosen for this study, in order to compensate for any dropouts during the course of survey.

4.4 Research methodology

Construction/design issues*:*

Phase 1 of this research involved exploring construction administration documents, in order to gather construction and design issues that affected the construction process. Six structural firms were visited and the twelve engineers in charge of construction for each of these firms were interviewed. Shop drawings of construction material were reviewed, and questions raised by suppliers and sub-contractors on the preparation of shop drawings were investigated. Next, official Requests for Information from general contractors, sub-contractors and suppliers to the Engineer or Architect in charge were investigated; tabulation was created of the construction/design issues and common problems. This chart was documented for evaluation and suggestion by experts. (For the list of structures reviewed and RFI identified see appendix D).

Initial expert interview

After the construction administration documents were investigated, Engineers in charge of specific projects were interviewed. Their input and comments on the construction/design issues were documented for evaluation.

Identifying classification for construction/design issues

Gathered issues were tabulated with additional questions and discussed and evaluated with selected experts to identify the most important construction/design issues affecting the construction process using Delphi method (See Appendix A).

Selection of panel of expert

A panel of experts including Architects and Registered Professional Engineers (PE) with a minimum of 10 years experience and knowledge of the construction process, and General Contractors with 15 years of construction experience in the construction process was selected to evaluate these construction/design issues.

Develop the initial framework

The initial framework for the Owner's Project Requirements (OPR) was developed by investigating documents for building commissioning, Guideline 0-2005, and available OPR established in Guidelines 1 and 3. See Table F.1 for the items used which are shown in *italic.*

Classification of construction/design issues

The gathered construction/design issues which were over and beyond the issues identified in the initial OPR for the Total Structural Systems were investigated and classified in three separate groups. Group one was identified as construction/design issues that are over and beyond the requirement of the applicable building codes and engineering principles. Group two was identified as construction/design issues that are caused by contract and construction document ambiguity. Group three was identified as construction/design issues that are caused by questionable quality in the construction process and design documents

Develop suggested OPRTSS

Classified construction/design issues were investigated and group one and two were added to the initial OPR to develop the suggested Owner's Project Requirements for the Total Structural Systems (OPRTSS).

Verification and Validation of OPRTSS

A questionnaire was designed and sent to the panel of experts for them to use to validate the suggested OPRTSS. The answered questionnaires were analyzed and the suggested OPRTSS was modified to create the final OPRTSS. The final OPRTSS was sent to the panel of experts for the verification and validation to certify that the final OPRTSS is inclusive per direction of Delphi method.

4.5. Research findings

In the course of visiting the offices of 6 structural firms, 30 projects were investigated for their Contract Administration issues. RFI logs were investigated in each office and items that impact structural performance tabulated (A list of these buildings is shown in Appendix D).

Construction/design issues

Issues found in Request for Information (RFI) reviews, interviews with experts and a review of change orders faced during the construction process were separated into three groups. Group one consists of those construction/design issues that are caused by the Owner's additional requirement relating to tenant's requests, future considerations or end-users' comfort and desires. Group two consists of those issues that are caused by contract and construction document ambiguity where the responsible parties are not clearly defined. Group three consist of those issues that are caused by construction quality, deficiencies and quality control in the construction process of the structural portion of the project. Group one and group two issues were evaluated and are added to the OPR to prevent their occurrence in the construction process. Group three issues were evaluated and added to this research. By using the knowledge of experts some of the construction/design issues identified in this research were added to OPRTSS.

Summary of RFI list found in different types of construction.

Concrete Structures issues identified in this research.

1) Dimensional clarification for column layout.
2) Reinforcing concrete cover.
3) Clarification between concrete and masonry block shear walls.
4) Clarification for type of drilled shafts.
5) Dimensional clarification.
6) Information on elevator pit's reinforcing.
7) Misplaced drilled pier.
8) Modification for steel cage in a pile.
9) Design change due to rock encounter.
10) Misplaced column dowels.
11) Misplaced reinforcing for retaining wall.
12) Reinforcing clarification for a matt foundation.
13) Rock anchor for a drilled pier.

14) Detail for block-outs in a vault.

15) Slab reinforcing for elevator pit.

16) Shear wall block-out for elevator rails.

17) Left out reinforcing for a masonry block wall.

18) Fix detail for column poured too short.

19) Missing duct openings.

20) Plumbing detail through structure.

21) Missing support for shaft wall.

22) Slab depression detail request.

23) Misplaced structural column.

24) Revision for footing due to rock encounter.

25) Misplaced barrier cable support embeds.

26) Remedy detail for missed expansion joint.

27) Opening for trash shoot in floor and concrete wall.

28) Stressing sequence for transfer beam.

29) Detail for light pole support.

30) Detail for shear wall thickness transition.

31) Elevator pit dimensional clarification.

32) Clarification for grout use.

33) Barrier cable attachment detail in a beam/column joint.

34) Support for cooling tower.

35) Misplaced dowel for screen wall.

36) Brick support detail.

37) Clarification for in-correct column dimension.

38) Detail for missed HVAC penetration in slab.

39) Remedy for stair beam.

40) Slab core for condensers.

41) Detail for elevator platform.

42) Detail for steel roof framing over duct shaft.

43) Slab edge connection detail for pre-fabricated stairs.

44) Canopy steel connection.

45) Curtain wall information and details.

46) Crane connection at floors.

Steel Structures issues identified in this research.

1) Dimensional clarification.

2) Provide required spacing for construction joints in the slab on grade.

3) Curtain wall design and connection.

4) Pre-cast detail and bracing size and interval.

5) Window washing support clarification.

6) Remedy for Misplaced anchor bolts.

7) Missing information on base plate detail.

8) Rain leader location.

9) Missing structural member sizes.

10) Bracing spacing clarification.

11) Roof penetration detail.

12) Location of stepped footing due to grade change.

13) Elevator support beam sizes.

14) Top of steel elevation clarification.

15) Pour stop detail.

16) Cooling tower support steel clarification.

17) Request for steel deck connection.

18) Mechanical equipment support location.

19) Remedy detail for Misplaced footing.

20) Remedy detail for short fabricated steel beam.

21) Remedy for misplaced embed plates.

22) Detail for antenna connection.

23) Location of elevator openings.

Mixed use Structures (Concrete transfer slab with Structural steel above) issues identified in this research.

1) Dimensional clarification for column layout

2) Clarification for grout type for auger cast pile.

3) Dimensional clarification.

4) Information on elevator pit's reinforcing.

5) Misplaced drilled pier.

6) Modification for steel cage in a pile.

7) Misplaced column dowels.

8) Misplaced reinforcing for retaining wall.

9) Reinforcing clarification for a matt foundation.

10) Slab reinforcing for elevator pit.

11) Provide required spacing for construction joints in the slab on grade.

12) Plumbing detail through structure.

13) Slab depression detail request.

14) Misplaced barrier cable support embeds.

15) Opening for trash shoot in floors.

16) Brick support detail.

17) Clarification for in-correct column dimension.

18) Detail for missed HVAC penetration in slab.

19) Remedy for stair beam.

20) Slab core for condensers.

21) Detail for elevator platform.

22) Detail for steel roof framing over duct shaft.

23) Slab edge connection detail for pre-fabricated stairs.

24) Canopy steel connection.

25) Curtain wall information and details.

26) Please provide design and details for pipe bollards located in the PT slabs.

27) Remedy detail where plumbing hits structural support.

28) Provide spacing for prefabricated wall to slab connection.

29) Provide sequence for staged post-tensioning.

30) Provide stair and elevator support details.

Group I issues (Performance indicators)

Group one classification developed in this research consists of those issues that are over and beyond the requirement of applicable building codes or Engineering principles. They are the owner's additional requirement due to market demand, future consideration and tenants' requests. These performance indicators were identified in the expert's in-depth interviews. These items were investigated in details for their importance and are summarized below:

1) Deflection

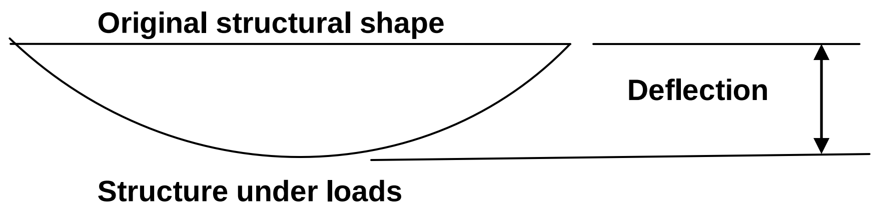


Figure 4.1 Structural Behaviors under Gravity Loads

- Structure may deflect in excess of end user's anticipation, or end-users' requirements.
- Structural support members need to be designed for additional Owner/end user's requirement to limit structural movement due to gravity loads.

2) Flatness / Levelness:

- Concrete floors are not finished flat per the Owner/end user's expectation.
- Concrete floor or roof is not finished level per the Owner/end user's expectation.

3) Future expansions.

- Structural loads and connections for future expansion and anticipated structural support shall be considered. All foundation and vertical support including lateral load resisting system shall be designed for future expansion.

4) Vibration:

- Structure has vibration over and beyond Owner/end user's expectation, when exposed to gravity, lateral or mechanical equipment loads

5) Noise due to structure's behavior:

- Noise transmitted through structures due to structural movement or finishes.

6) Prevention of progressive collapse.

- Structure collapses due to failure of an element or terrorist activities.

Group II issues

Group two classification developed in this research consists of those issues that are caused by contract and construction document ambiguity where the responsible parties are not clearly defined:

1) Structural support for window washing

- Construction/design issue - Addition of support for window washing after finishing roof will effect time and cost.
- Construction solution - Location and type of supports should be properly detailed and dimensioned in construction documents.

2) Structural supports for elevators and stair

- Construction/design issue - Addition of support for elevators and stairs will effect time and cost.
- Construction solution - Location and type of supports should be properly detailed and dimensioned in construction documents.

3) Structural supports for ornamental items and brick facades.

4) Issues due to grading:

- Structural drawing and grading plan are not coordinated. Missing proper structural details.

5) Site walls

- Structural drawing and grading plan are not coordinated. Missing structure.

6) Underground utility structure issues

7) Dimensional conflicts

- Missing coordination between Architectural and structural drawings.

8) Misaligned dowels

9) Issues with design of curtain walls

10) Vertical expansion joints in structural concrete walls and finish stucco

11) Horizontal expansion joints in slab on grades and finish stucco

12) Special loadings

- Loading for special equipment not specified.

13) Underground pipes penetrating buildings.

- Structural drawings and utility drawings not coordinated for underground pipes.

14) Control joints in slab on grade

- Lack of construction/control joints in slab on grade creates concrete cracks in un-desired areas.

15) Structural fire protections

- Structural protection against fire that may cause premature structural failure in case of fire.

16) Frost penetrations

- Frost depth is not provided; may cause structural settlement due to freeze and thaws.

17) Lights and pole support are not provided.

18) Supports for barrier cables in parking structures are not provided.

19) Mechanical equipment supports are not provided.

20) Top of steel elevation not specified in floors and roof.

21) Metal deck connection for diaphragms support is not provided.

22) Area used for storage not specified for design of structural supports.

Group III issues

Group three classification developed in this research consists of those issues that are caused by construction quality, deficiencies and quality control in the construction process of the structural portion of the project.

1) Floor/Roof penetration/openings
2) Vertical column alignment
3) Dimensional conflict
4) Misaligned dowels
5) Horizontal and vertical expansion joints.
6) Special loading
7) Control joints in slab on grade
8) Structural fire protections
9) Foundation frost penetration

10) Mechanical equipment support

11) Top of steel elevation

12) Top of floor elevation

13) Metal deck connection to structure

14) Floor/Roof penetration/openings

- Construction/design issue - Openings in the floor and roof for all utility functions.
- Construction solution - Add a floor and roof plan to show all openings required by construction team.

15) Vertical column alignment

- Structural issue - Un-aligned vertical elements in structure will weaken vertical elements due to eccentricity
- Construction solution - Add dimensional plans for column location which specifies column coordination for field accuracy.

Table 4.1 Group I issues (performance indicators)

Group I issues
Deflection
Flatness / Levelness
Future expansions
Vibration
Noise due to structure's behavior
Progressive collapse

Table 4.2 Group II construction/design issues

Group II issues	Identified in concrete buildings	Identified in steel buildings	Identified in mixed use
Structural support for window washing	3/15 = 20%	2/8 = 25%	2/7 = 30%
Structural supports for elevators	6/15 = 40%	6/8 = 75%	5/7 = 70%
Stair and handrail design	0/15 = 0%	7/8 = 90%	6/7 = 90%
Structural supports for ornamental items, brick facades	3/15 = 20%	6/8 = 75%	5/7 = 70%
Issues due to grading	3/15 = 20%	5/8 = 60%	4/7 = 60%
Underground utility structure issues	6/15 = 40%	3/8 = 38%	2/7 = 30%
Underground pipes to building penetrations	8/15 = 56%	5/8 = 60%	4/7 = 60%
Structural fire	2/15 = 14%	6/8 = 75%	4/7 = 60%

Table 4.2 continued

Group II issues	Identified in concrete buildings	Identified in steel buildings	Identified in mixed use
protections			
Lights, pole and sign support and design.	6/15 = 40%	3/8 = 38%	3/7 = 42%
Supports for barrier cables in parking structures are not provided.	3/15 = 20%	2/8 = 25%	2/7 = 30%
Area used for storage not specified for structural support.	2/15 = 14%	2/8 = 25%	1/7 = 15%
Curtain Wall design	5/15 = 33%	6/8 = 75%	5/7 = 70%

Table 4.3 Group III construction/design issues

Group III issues	Identified in concrete buildings	Identified in steel buildings	Identified in mixed use
Floor/Roof penetration/openings	10/15 = 67%	6/8 = 75%	5/7 = 70%
Vertical column alignment	8/15 = 56%	6/8 = 75%	5/7 = 70%
Dimensional conflict	15/15 = 100%	8/8 = 100%	7/7 = 100%
Miss aligned dowels	12/15 = 80%	0/8 = 0%	4/7 = 60%
Horizontal and vertical expansion joints.	8/15 = 56%	0/8 = 0%	4/7 = 60%
Special loading	5/15 = 33%	3/8 = 38%	5/7 = 70%
Control joints in slab on grade	6/15 = 40%	5/8 = 60%	4/7 = 60%

Table 4.3 continued

Group III issues	Identified in concrete buildings	Identified in steel buildings	Identified in mixed use
Structural fire protections	2/15 = 14%	6/8 = 75%	4/7 = 60%
Foundation frost penetration	3/15 = 20%	5/8 = 60%	3/7 = 42%
Mechanical equipment support	2/15 = 14%	6/8 = 75%	5/7 = 70%
Top of steel elevation	0/15 = 0%	7/8 = 90%	5/7 = 70%
Top of floor elevation	5/15 = 33%	7/8 = 90%	5/7 = 70%
Metal deck connection to structure	0/15 = 0%	6/8 = 75%	3/7 = 42%

4.5 Example of Case developed in this research for group I issues and suggested solution

Deflection:

a) Concrete buildings

- Slabs

  - Allowable deflection by code is defined by the following formula (1):

    Where:

    w = uniform loads imposed (Live + Dead)

    L = Span

E = Modulus of elasticity

I = Section modulus (ASCE, 2007)

Assume a 12" wide concrete slab that spans 'l' feet and

– In psi

E = 3.6 x 10^6 psi (for f'_C = 4000 psi normal weight concrete)

We calculate a thickness to be able to come up with the imposed dead load with t=l*12/30 = l/2.5

I = $bt^3/12$ where b = 12"

W = ((l/2.5) x 150/12) + 70

We substitute all known factors in equation (1) to calculate an approximate deflection

$\Delta = (L^2)/1000$.

With this approximate deflection we can come up with a table for different span.

Table 4.4 - Span Thickness Ratio for Slab

Span	**Slab Thickness**	**Deflection l/a, a =**	**Additional thickness to reach l/600**	**Cost**
15 feet	6"	900	0	0
20 feet	8"	800	0	0

Table 4.4 continued

Span	**Slab Thickness**	**Deflection l/a, a =**	**Additional thickness to reach l/600**	**Cost**
25 feet	10”	685	0	0
30 feet	12”	600	0	0
35 feet	14”	535	¾” added	$0.20/ Ft^2

Normal concrete structures will not have spans over 32 feet

- Beams
  - Assuming that the concrete structure will have equal dimensions in both direction of the structure, same calculation and deflection criteria is used to create a similar table for concrete beams, assuming beam width of 18 inches.

Table 4.5 - Span Thickness Ratio for Concrete Beams

Span	Beam depth	Deflection l/a, a =	Additional thickness to reach l/600	Cost
15 feet	12”	240	4”	$0.07/ Ft^2$
20 feet	15”	240	5”	$0.07/ Ft^2$
25 feet	20”	240	7”	$0.14/ Ft^2$
30 feet	24”	240	9”	$0.14/ Ft^2$
35 feet	30”	240	12”	$0.14/ Ft^2$.

As it shown in Table 3.2, in order to limit beam deflection to l/600, approximately 14 cents per horizontal elevated slab area will be added to the cost of construction.

b) Steel buildings – Assuming buildings with pan filled concrete of approximately 4” thickness supported on bar joists spaces at 30 inches on center and structural girders.

- Slabs - the deflection on the slab is way beyond l/600 thus there is no cost increase for slabs
- Bar joists

  Secondary structural support for floor slabs
- Beams:

  Primary structural support for floors.

Table 4.6 - Span Depth Ratio for Bar Joists

Span	**Bar joist**	**Deflection l/a, a =**	**Additional weight to reach l/480**	**Cost**
20 feet	16 K2	240	1.0	$0.50/ Ft^2
25 feet	20 K4	320	1.2	$0.60/ Ft^2
30 feet	28 K6	320	1.5	$0.75/ Ft^2
35 feet	28 K7	240	2.0	$1.00/ Ft^2
40 feet	30 K10	240	2.5	$1.25/ Ft^2

Table 4.7 Span depth ratio for Beams

Span	Steel beam	Deflection l/a, a =	Additional weight to reach l/600	Cost
20 feet	W 21x44	600	0	0
25 feet	W 21x50	300	1.0	\$0.50/ Ft^2
30 feet	W 24x76	310	1.0	\$0.50/ Ft^2
35 feet	W 30x90	285	1.3	\$0.65/ Ft^2
40 feet	W 33x118	275	1.7	\$0.85/ Ft^2

CHAPTER 5

PERFORMANCE ASSESSMENT BASED ON EXPERT JUDGMENTS

5.1 Purpose

This chapter is aimed at assessing the performance of each section of the suggested OPRTSS. When the suggested OPRTSS was designed, the base of the OPRTSS was the recommended OPR by Guideline 0-2005. The tabulated and analyzed construction/design issues were used to add additional sections to the OPR to develop the OPRTSS. A questionnaire was designed to evaluate the impact of each section of the OPRTSS on the structural performance of a project using the knowledge of experts. The performance assessment is performed by soliciting the judgments of experts through use of the Delphi technique.

At the conclusion, a summary of overall results and their implications will be provided.

5.2 Survey Results

The initial questionnaire identified the construction/design issues that were causing delays, confusions and ambiguities in contract documents. The second questionnaire was designed for the experts to rank each section of the OPRTSS by the section's impact on the structural performance. Figure 5.1 shows the structured response as is described by the Likert Scale.

Please mark your answer.

No Impact		**Moderate Impact**		**Extreme Impact**
1	**2**	**3**	**4**	**5**

Figure 5.1 Likert Scale

After receipt of the questionnaire; the sections in the OPRTSS were divided into three groups. The First Group is the sections created using the recommended OPR by the Guideline 0-2005. The Second Group, which is called Group A, is the sections that were added to the OPRTSS as a result of the research. These sections were labeled as Group One in the research. Group One construction/design issues consist of those issues that are not defined or required by applicable building codes and are the owner's additional requirement due to market demand, future consideration and tenant's requests. The last group is another group of sections that were added to the OPRTSS as a result of the research. These sections were labeled as Group Two. Group Two construction/design issues consist of those issues that are caused by contract and construction document ambiguity where the responsible parties were not clearly defined.

The criteria used for analyzing the results of the study were to evaluate each section of the OPRTSS by the responses received from the panel of experts. Each member on the panel of experts was asked to evaluate each section of the OPRTSS and express the impact of each section (from scale of 1 to 5) on the structural performance of projects. For the first comparison, the added percentage of responses for moderate impact to extreme impact (scales of 3 to 5) was compared to the total percentage of responses for no impact to low impact sections (scales 1 and 2). The second comparison was made by addition of percentages to responses of high impact to extreme impact (scales 4 and 5) to the total percentage of responses for no impact to low impact sections (scales 1 and 2). These comparisons indicated the impacts of each section on structural performance and enabled the researcher to identify sections by their importance.

The data gathered from the survey was tabulated into three groups. Group one is the sections developed using the recommendations of Guideline 0-2005. Group two, (called Group A), is the sections developed using construction/design issues identified by interviews with experts. Group three (called Group B) is the sections developed using construction/design issues identified by reviewing construction documents. These groups are shown in Tables 5.1 through 5.5. The first five columns are percentages used by respondent for impact values of 1 to 5, column 6 is the sections, column 7 is the summation of columns 1 and 2 and the last column is a summation of either columns 3,4 and 5 or columns 4 and 5 (See Tables 5.1 to 5.7).

Table 5.1 Results of the questionnaire 2 for sections recommended by Guideline 0-2005

Percentage used					Sec #	∑ 1+2	∑ 3+4+5
1.00	2.00	3.00	4.00	5.00			
0.00	0.00	13.33	20.00	66.67	1	0.00	100.00
0.00	6.67	20.00	40.00	33.33	2	6.67	93.33
0.00	0.00	6.67	26.67	66.67	3	0.00	100.00
20.00	13.33	33.33	26.67	6.67	4	33.33	66.67
0.00	40.00	40.00	13.33	6.67	5	40.00	60.00
0.00	33.33	26.67	40.00	0.00	6	33.33	66.67
13.33	0.00	53.33	13.33	20.00	7	13.33	86.67
13.33	13.33	6.67	40.00	26.67	8	26.67	73.33
20.00	13.33	26.67	33.33	6.67	9	33.33	66.67
13.33	13.33	13.33	46.67	13.33	10	26.67	73.33
26.67	26.67	13.33	13.33	20.00	11	53.33	46.67
33.33	20.00	13.33	13.33	20.00	12	53.33	46.67
6.67	20.00	0.00	20.00	53.33	14	26.67	73.33
0.00	13.33	26.67	6.67	53.33	15	13.33	86.67
6.67	20.00	20.00	13.33	40.00	16	26.67	73.33
0.00	13.33	6.67	66.67	13.33	18	13.33	86.67
13.33	6.67	33.33	40.00	6.67	19	20.00	80.00
0.00	6.67	6.67	40.00	46.67	20	6.67	93.33
0.00	0.00	0.00	26.67	73.33	21	0.00	100.00
0.00	0.00	13.33	53.33	33.33	22	0.00	100.00
0.00	6.67	0.00	60.00	33.33	23	6.67	93.33
6.67	26.67	13.33	13.33	40.00	24	33.33	66.67

Table 5.1 continued

Percentage used					Sec #	∑	∑
1.00	2.00	3.00	4.00	5.00		1+2	3+4+5
13.33	26.67	13.33	46.67	0.00	25	40.00	60.00
53.33	6.67	6.67	33.33	0.00	26	60.00	40.00
20.00	13.33	20.00	40.00	6.67	27	33.33	66.67
26.67	13.33	33.33	20.00	6.67	28	40.00	60.00
0.00	13.33	26.67	33.33	26.67	29	13.33	86.67
0.00	13.33	26.67	40.00	20.00	30	13.33	86.67
0.00	6.67	6.67	53.33	33.33	31	6.67	93.33
6.67	20.00	33.33	40.00	0.00	32	26.67	73.33
0.00	6.67	0.00	0.00	93.33	33	6.67	93.33
0.00	0.00	6.67	6.67	86.67	35	0.00	100.00
0.00	0.00	6.67	20.00	73.33	36	0.00	100.00
0.00	0.00	0.00	6.67	93.33	37	0.00	100.00
0.00	0.00	6.67	20.00	73.33	39	0.00	100.00
0.00	6.67	0.00	46.67	46.67	40	6.67	93.33
0.00	0.00	13.33	13.33	73.33	41	0.00	100.00
0.00	0.00	6.67	26.67	66.67	42	0.00	100.00
6.67	0.00	13.33	13.33	66.67	43	6.67	93.33
6.67	0.00	6.67	40.00	46.67	44	6.67	93.33
6.67	0.00	20.00	53.33	20.00	45	6.67	93.33
6.67	0.00	6.67	26.67	60.00	46	6.67	93.33
0.00	0.00	0.00	33.33	66.67	47	0.00	100.00
0.00	0.00	0.00	26.67	73.33	48	0.00	100.00
0.00	6.67	13.33	33.33	46.67	49	6.67	93.33

Table 5.1 continued

Percentage used					Sec #	∑ 1+2	∑ 3+4+5
1.00	2.00	3.00	4.00	5.00			
0.00	6.67	6.67	33.33	53.33	50	6.67	93.33
0.00	0.00	0.00	33.33	66.67	53	0.00	100.00
0.00	0.00	6.67	26.67	66.67	54	0.00	100.00
0.00	0.00	20.00	40.00	40.00	55	0.00	100.00
13.33	13.33	13.33	6.67	53.33	57	26.67	73.33
0.00	0.00	13.33	40.00	46.67	59	0.00	100.00
6.67	33.33	53.33	6.67	0.00	67	40.00	60.00
13.33	26.67	53.33	6.67	0.00	69	40.00	60.00
13.33	33.33	46.67	6.67	0.00	72	46.67	53.33
13.33	33.33	53.33	0.00	0.00	82	46.67	53.33
13.33	26.67	46.67	13.33	0.00	94	40.00	60.00
40.00	26.67	6.67	20.00	6.67	96	66.67	33.33
0.00	0.00	53.33	13.33	33.33	97	0.00	100.00
13.33	26.67	53.33	6.67	0.00	104	40.00	60.00
6.67	0.00	20.00	46.67	26.67	108	6.67	93.33
13.33	33.33	40.00	13.33	0.00	110	46.67	53.33
13.33	26.67	53.33	6.67	0.00	115	40.00	60.00
20.00	40.00	40.00	0.00	0.00	127	60.00	40.00

Table 5.2 Results of the questionnaire 2 for sections used in Group A

Percentage used					Sec #	∑ 1+2	∑ 3+4+5
1.00	2.00	3.00	4.00	5.00			
0.00	0.00	13.33	13.33	73.33	34	0.00	100.00
0.00	0.00	6.67	33.33	60.00	56	0.00	100.00
0.00	0.00	6.67	6.67	86.67	58	0.00	100.00
0.00	0.00	13.33	66.67	20.00	80	0.00	100.00
0.00	0.00	6.67	53.33	40.00	81	0.00	100.00
0.00	0.00	26.67	53.33	20.00	86	0.00	100.00
0.00	0.00	33.33	40.00	26.67	87	0.00	100.00
0.00	0.00	40.00	26.67	33.33	88	0.00	100.00
0.00	6.67	0.00	33.33	60.00	90	6.67	93.33
0.00	0.00	13.33	66.67	20.00	91	0.00	100.00
0.00	6.67	6.67	60.00	26.67	95	6.67	93.33
0.00	0.00	6.67	53.33	40.00	103	0.00	100.00
0.00	6.67	20.00	26.67	46.67	105	6.67	93.33
13.33	13.33	6.67	53.33	13.33	112	26.67	73.33
0.00	0.00	6.67	53.33	40.00	114	0.00	100.00
0.00	0.00	6.67	26.67	66.67	128	0.00	100.00
0.00	0.00	0.00	53.33	46.67	129	0.00	100.00
0.00	0.00	0.00	66.67	33.33	130	0.00	100.00
0.00	6.67	40.00	40.00	13.33	131	6.67	93.33
0.00	0.00	0.00	53.33	46.67	132	0.00	100.00
0.00	0.00	40.00	33.33	26.67	133	0.00	100.00
0.00	0.00	20.00	40.00	40.00	134	0.00	100.00

Table 5.3 Results of the questionnaire 2 for sections used in Group B

Percentage used					Sec #	∑ 1+2	∑ 3+4+5
1.00	2.00	3.00	4.00	5.00			
0.00	0.00	0.00	33.33	66.67	13	0.00	100.00
0.00	0.00	13.33	26.67	60.00	38	0.00	100.00
0.00	6.67	6.67	20.00	66.67	51	6.67	93.33
6.67	0.00	13.33	53.33	26.67	52	6.67	93.33
6.67	6.67	20.00	40.00	26.67	60	13.33	86.67
6.67	0.00	0.00	33.33	60.00	61	6.67	93.33
6.67	0.00	26.67	40.00	26.67	62	6.67	93.33
13.33	20.00	13.33	40.00	13.33	63	33.33	66.67
13.33	0.00	0.00	60.00	26.67	64	13.33	86.67
6.67	0.00	13.33	40.00	40.00	65	6.67	93.33
0.00	0.00	13.33	26.67	60.00	66	0.00	100.00
0.00	0.00	13.33	13.33	73.33	68	0.00	100.00
6.67	6.67	20.00	46.67	20.00	70	13.33	86.67
0.00	6.67	26.67	33.33	33.33	71	6.67	93.33
6.67	6.67	33.33	40.00	13.33	73	13.33	86.67
6.67	0.00	20.00	46.67	26.67	74	6.67	93.33
13.33	6.67	13.33	53.33	13.33	75	20.00	80.00
0.00	0.00	40.00	40.00	20.00	76	0.00	100.00
6.67	0.00	20.00	26.67	46.67	77	6.67	93.33
6.67	0.00	6.67	20.00	66.67	78	6.67	93.33
6.67	6.67	6.67	53.33	26.67	79	13.33	86.67
6.67	6.67	20.00	40.00	26.67	83	13.33	86.67

Table 5.3 continued

Percentage used					Sec #	∑ 1+2	∑ 3+4+5
1.00	2.00	3.00	4.00	5.00			
0.00	0.00	13.33	53.33	33.33	84	0.00	100.00
6.67	0.00	0.00	33.33	60.00	85	6.67	93.33
0.00	0.00	0.00	53.33	46.67	89	0.00	100.00
0.00	0.00	0.00	40.00	60.00	92	0.00	100.00
0.00	0.00	6.67	53.33	40.00	93	0.00	100.00
6.67	0.00	13.33	53.33	26.67	98	6.67	93.33
0.00	0.00	0.00	60.00	40.00	99	0.00	100.00
0.00	13.33	13.33	40.00	33.33	100	13.33	86.67
0.00	0.00	26.67	60.00	13.33	101	0.00	100.00
0.00	0.00	6.67	53.33	40.00	102	0.00	100.00
6.67	0.00	13.33	40.00	40.00	106	6.67	93.33
6.67	6.67	33.33	40.00	13.33	107	13.33	86.67
6.67	6.67	26.67	33.33	26.67	109	13.33	86.67
13.33	0.00	0.00	13.33	73.33	111	13.33	86.67
6.67	0.00	6.67	40.00	46.67	113	6.67	93.33
6.67	6.67	40.00	40.00	6.67	116	13.33	86.67
6.67	6.67	13.33	33.33	40.00	117	13.33	86.67
40.00	13.33	13.33	33.33	0.00	118	53.33	46.67
53.33	6.67	13.33	20.00	6.67	119	60.00	40.00
13.33	13.33	13.33	40.00	20.00	120	26.67	73.33
13.33	13.33	6.67	46.67	20.00	121	26.67	73.33
0.00	0.00	33.33	46.67	20.00	122	0.00	100.00
0.00	0.00	46.67	33.33	20.00	123	0.00	100.00

Table 5.3 continued

Percentage used					Sec #	∑ 1+2	∑ 3+4+5
1.00	2.00	3.00	4.00	5.00			
0.00	0.00	26.67	40.00	33.33	124	0.00	100.00
6.67	0.00	20.00	46.67	26.67	125	6.67	93.33
6.67	6.67	26.67	46.67	13.33	126	13.33	86.67

Table 5.4 Results of the questionnaire 2 for sections recommended by Guideline0-2005

Percentage used					Sec #	∑ 1+2	∑ 4+5
1.00	2.00	3.00	4.00	5.00			
0.00	0.00	13.33	20.00	66.67	1	0.00	86.67
0.00	6.67	20.00	40.00	33.33	2	6.67	73.33
0.00	0.00	6.67	26.67	66.67	3	0.00	93.33
20.00	13.33	33.33	26.67	6.67	4	33.33	33.33
0.00	40.00	40.00	13.33	6.67	5	40.00	20.00
0.00	33.33	26.67	40.00	0.00	6	33.33	40.00
13.33	0.00	53.33	13.33	20.00	7	13.33	33.33
13.33	13.33	6.67	40.00	26.67	8	26.67	66.67
20.00	13.33	26.67	33.33	6.67	9	33.33	40.00
13.33	13.33	13.33	46.67	13.33	10	26.67	60.00
26.67	26.67	13.33	13.33	20.00	11	53.33	33.33
33.33	20.00	13.33	13.33	20.00	12	53.33	33.33
6.67	20.00	0.00	20.00	53.33	14	26.67	73.33
0.00	13.33	26.67	6.67	53.33	15	13.33	60.00
6.67	20.00	20.00	13.33	40.00	16	26.67	53.33
0.00	13.33	6.67	66.67	13.33	18	13.33	80.00
13.33	6.67	33.33	40.00	6.67	19	20.00	46.67
0.00	6.67	6.67	40.00	46.67	20	6.67	86.67
0.00	0.00	0.00	26.67	73.33	21	0.00	100.00

Table 5.4 continued

Percentage used					Sec #	∑ 1+2	∑ 4+5
1.00	2.00	3.00	4.00	5.00			
0.00	0.00	13.33	53.33	33.33	22	0.00	86.67
0.00	6.67	0.00	60.00	33.33	23	6.67	93.33
6.67	26.67	13.33	13.33	40.00	24	33.33	53.33
13.33	26.67	13.33	46.67	0.00	25	40.00	46.67
53.33	6.67	6.67	33.33	0.00	26	60.00	33.33
20.00	13.33	20.00	40.00	6.67	27	33.33	46.67
26.67	13.33	33.33	20.00	6.67	28	40.00	26.67
0.00	13.33	26.67	33.33	26.67	29	13.33	60.00
0.00	13.33	26.67	40.00	20.00	30	13.33	60.00
0.00	6.67	6.67	53.33	33.33	31	6.67	86.67
6.67	20.00	33.33	40.00	0.00	32	26.67	40.00
0.00	6.67	0.00	0.00	93.33	33	6.67	93.33
0.00	0.00	6.67	6.67	86.67	35	0.00	93.33
0.00	0.00	6.67	20.00	73.33	36	0.00	93.33
0.00	0.00	0.00	6.67	93.33	37	0.00	100.00
0.00	0.00	6.67	20.00	73.33	39	0.00	93.33
0.00	6.67	0.00	46.67	46.67	40	6.67	93.33
0.00	0.00	13.33	13.33	73.33	41	0.00	86.67
0.00	0.00	6.67	26.67	66.67	42	0.00	93.33
6.67	0.00	13.33	13.33	66.67	43	6.67	80.00
6.67	0.00	6.67	40.00	46.67	44	6.67	86.67
6.67	0.00	20.00	53.33	20.00	45	6.67	73.33
6.67	0.00	6.67	26.67	60.00	46	6.67	86.67
0.00	0.00	0.00	33.33	66.67	47	0.00	100.00
0.00	0.00	0.00	26.67	73.33	48	0.00	100.00
0.00	6.67	13.33	33.33	46.67	49	6.67	80.00
0.00	6.67	6.67	33.33	53.33	50	6.67	86.67

Table 5.4 continued

Percentage used					Sec #	∑	∑
1.00	2.00	3.00	4.00	5.00		1+2	4+5
0.00	0.00	0.00	33.33	66.67	53	0.00	100.00
0.00	0.00	6.67	26.67	66.67	54	0.00	93.33
0.00	0.00	20.00	40.00	40.00	55	0.00	80.00
13.33	13.33	13.33	6.67	53.33	57	26.67	60.00
0.00	0.00	13.33	40.00	46.67	59	0.00	86.67
6.67	33.33	53.33	6.67	0.00	67	40.00	6.67
13.33	26.67	53.33	6.67	0.00	69	40.00	6.67
13.33	33.33	46.67	6.67	0.00	72	46.67	6.67
13.33	33.33	53.33	0.00	0.00	82	46.67	0.00
13.33	26.67	46.67	13.33	0.00	94	40.00	13.33
40.00	26.67	6.67	20.00	6.67	96	66.67	26.67
0.00	0.00	53.33	13.33	33.33	97	0.00	46.67
13.33	26.67	53.33	6.67	0.00	104	40.00	6.67
6.67	0.00	20.00	46.67	26.67	108	6.67	73.33
13.33	33.33	40.00	13.33	0.00	110	46.67	13.33
13.33	26.67	53.33	6.67	0.00	115	40.00	6.67
20.00	40.00	40.00	0.00	0.00	127	60.00	0.00

Table 5.5 Results of the questionnaire 2 for sections used in Group A

Percentage used					Sec #	∑ 1+2	∑ 4+5
1.00	2.00	3.00	4.00	5.00			
0.00	0.00	13.33	13.33	73.33	34	0.00	86.67
0.00	0.00	6.67	33.33	60.00	56	0.00	93.33
0.00	0.00	6.67	6.67	86.67	58	0.00	93.33
0.00	0.00	13.33	66.67	20.00	80	0.00	86.67
0.00	0.00	6.67	53.33	40.00	81	0.00	93.33
0.00	0.00	26.67	53.33	20.00	86	0.00	73.33
0.00	0.00	33.33	40.00	26.67	87	0.00	66.67
0.00	0.00	40.00	26.67	33.33	88	0.00	60.00
0.00	6.67	0.00	33.33	60.00	90	6.67	93.33
0.00	0.00	13.33	66.67	20.00	91	0.00	86.67
0.00	6.67	6.67	60.00	26.67	95	6.67	86.67
0.00	0.00	6.67	53.33	40.00	103	0.00	93.33
0.00	6.67	20.00	26.67	46.67	105	6.67	73.33
13.33	13.33	6.67	53.33	13.33	112	26.67	66.67
0.00	0.00	6.67	53.33	40.00	114	0.00	93.33
0.00	0.00	6.67	26.67	66.67	128	0.00	93.33
0.00	0.00	0.00	53.33	46.67	129	0.00	100.00
0.00	0.00	0.00	66.67	33.33	130	0.00	100.00
0.00	6.67	40.00	40.00	13.33	131	6.67	53.33
0.00	0.00	0.00	53.33	46.67	132	0.00	100.00
0.00	0.00	40.00	33.33	26.67	133	0.00	60.00
0.00	0.00	20.00	40.00	40.00	134	0.00	80.00

Table 5.6 Results of the questionnaire 2 for sections used in Group B

Percentage used					Sec #	∑ 1+2	∑ 4+5
1.00	2.00	3.00	4.00	5.00			
0.00	0.00	0.00	33.33	66.67	13	0.00	100.00
0.00	0.00	13.33	26.67	60.00	38	0.00	86.67
0.00	6.67	6.67	20.00	66.67	51	6.67	86.67
6.67	0.00	13.33	53.33	26.67	52	6.67	80.00
6.67	6.67	20.00	40.00	26.67	60	13.33	66.67
6.67	0.00	0.00	33.33	60.00	61	6.67	93.33
6.67	0.00	26.67	40.00	26.67	62	6.67	66.67
13.33	20.00	13.33	40.00	13.33	63	33.33	53.33
13.33	0.00	0.00	60.00	26.67	64	13.33	86.67
6.67	0.00	13.33	40.00	40.00	65	6.67	80.00
0.00	0.00	13.33	26.67	60.00	66	0.00	86.67
0.00	0.00	13.33	13.33	73.33	68	0.00	86.67
6.67	6.67	20.00	46.67	20.00	70	13.33	66.67
0.00	6.67	26.67	33.33	33.33	71	6.67	66.67
6.67	6.67	33.33	40.00	13.33	73	13.33	53.33
6.67	0.00	20.00	46.67	26.67	74	6.67	73.33
13.33	6.67	13.33	53.33	13.33	75	20.00	66.67
0.00	0.00	40.00	40.00	20.00	76	0.00	60.00
6.67	0.00	20.00	26.67	46.67	77	6.67	73.33
6.67	0.00	6.67	20.00	66.67	78	6.67	86.67
6.67	6.67	6.67	53.33	26.67	79	13.33	80.00
6.67	6.67	20.00	40.00	26.67	83	13.33	66.67
0.00	0.00	13.33	53.33	33.33	84	0.00	86.67
6.67	0.00	0.00	33.33	60.00	85	6.67	93.33
0.00	0.00	0.00	53.33	46.67	89	0.00	100.00
0.00	0.00	0.00	40.00	60.00	92	0.00	100.00

Table 5.6 continued

Percentage used					Sec #	∑ 1+2	∑ 4+5
1.00	2.00	3.00	4.00	5.00			
0.00	0.00	6.67	53.33	40.00	93	0.00	93.33
6.67	0.00	13.33	53.33	26.67	98	6.67	80.00
0.00	0.00	0.00	60.00	40.00	99	0.00	100.00
0.00	13.33	13.33	40.00	33.33	100	13.33	73.33
0.00	0.00	26.67	60.00	13.33	101	0.00	73.33
0.00	0.00	6.67	53.33	40.00	102	0.00	93.33
6.67	0.00	13.33	40.00	40.00	106	6.67	80.00
6.67	6.67	33.33	40.00	13.33	107	13.33	53.33
6.67	6.67	26.67	33.33	26.67	109	13.33	60.00
13.33	0.00	0.00	13.33	73.33	111	13.33	86.67
6.67	0.00	6.67	40.00	46.67	113	6.67	86.67
6.67	6.67	40.00	40.00	6.67	116	13.33	46.67
6.67	6.67	13.33	33.33	40.00	117	13.33	73.33
40.00	13.33	13.33	33.33	0.00	118	53.33	33.33
53.33	6.67	13.33	20.00	6.67	119	60.00	26.67
13.33	13.33	13.33	40.00	20.00	120	26.67	60.00
13.33	13.33	6.67	46.67	20.00	121	26.67	66.67
0.00	0.00	33.33	46.67	20.00	122	0.00	66.67
0.00	0.00	46.67	33.33	20.00	123	0.00	53.33
0.00	0.00	26.67	40.00	33.33	124	0.00	73.33
6.67	0.00	20.00	46.67	26.67	125	6.67	73.33
6.67	6.67	26.67	46.67	13.33	126	13.33	60.00

The Group one section was investigated using the tabulated responses received. A graph is drawn to show the validity of the sections based on percentages of approval. Responses 3, 4 and 5 were added as they all have moderate to extreme impact on structural performance, and responses 1 and 2 were added as they have little or no impact on structural performance. (See Figure 5.2).

This figure shows that a majority of the sections had the moderate to extreme impact of 60% or more. The sections with lower impact were sections that will only have minor impact on structural performance, the list of these sections are (These items shown red in the final OPRTSS):

1) Lab, Animal, or other special Deliveries and Services.
2) Ambulance and other Emergency services.
3) Energy conservation for sustainability.
4) LEED requirement for building materials.
5) Insulation for floors.

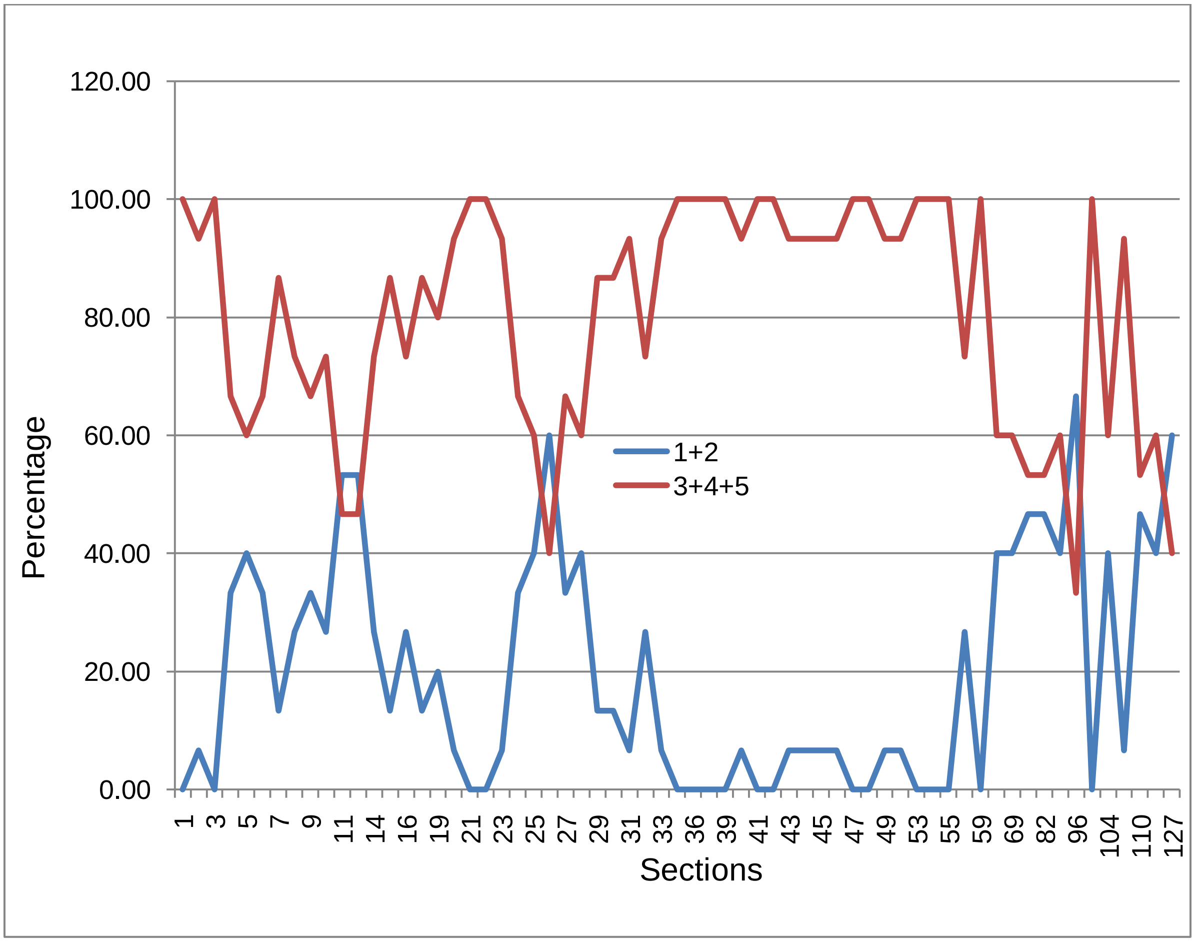


Figure 5.2 – Result of Guideline 0-2005 requirements for the OPRTSS

The Group A section was investigated using the tabulated responses received. A graph was drawn to show the validity of the sections based on percentage of approval. Responses 3, 4 and 5 were added as they all have moderate to extreme impact on structural performance. Responses 1 and 2 were added as they have little or no impact on structural performance. (See Figure 5.3).

This figure shows that all of the sections had moderate to extreme impact of 80% or more. This proves the result of the research and is validated by the expert panel as the items gathered by the research methodology have high impact on structural performance and should be addressed by the owner at the pre-design stage.

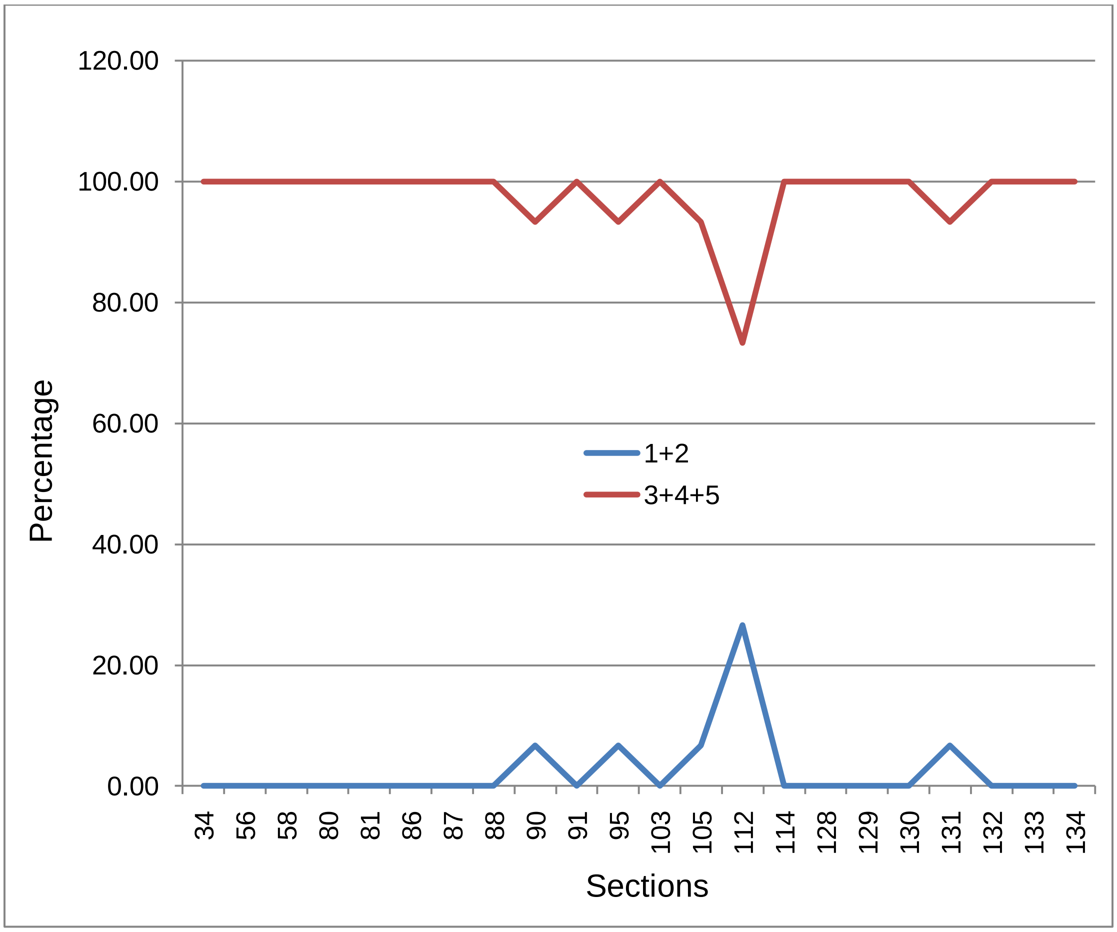


Figure 5.3 – Result of Group A requirements for the OPRTSS

The Group B section was investigated using the tabulated responses received and a graph was drawn to show the validity of the sections based on percentage of approval. Responses 3, 4 and 5 were added as they all have moderate to extreme impact on structural performance. Responses 1 and 2 were added as they have little or no impact on structural performance. (See Figure 5.4).

This figure shows that a majority of the sections had the moderate to extreme impact of 70% or more. This proves the result of the research and is validated by the expert panel as the items gathered by the research methodology have high impact on structural performance and should be addressed by the owner at the pre-design stage. There were two sections that had low impact on structural performance per the tabulated responses by the experts. These two sections were:

1) Responsible party for the design of paving.
2) Responsible party for the design of project sign.

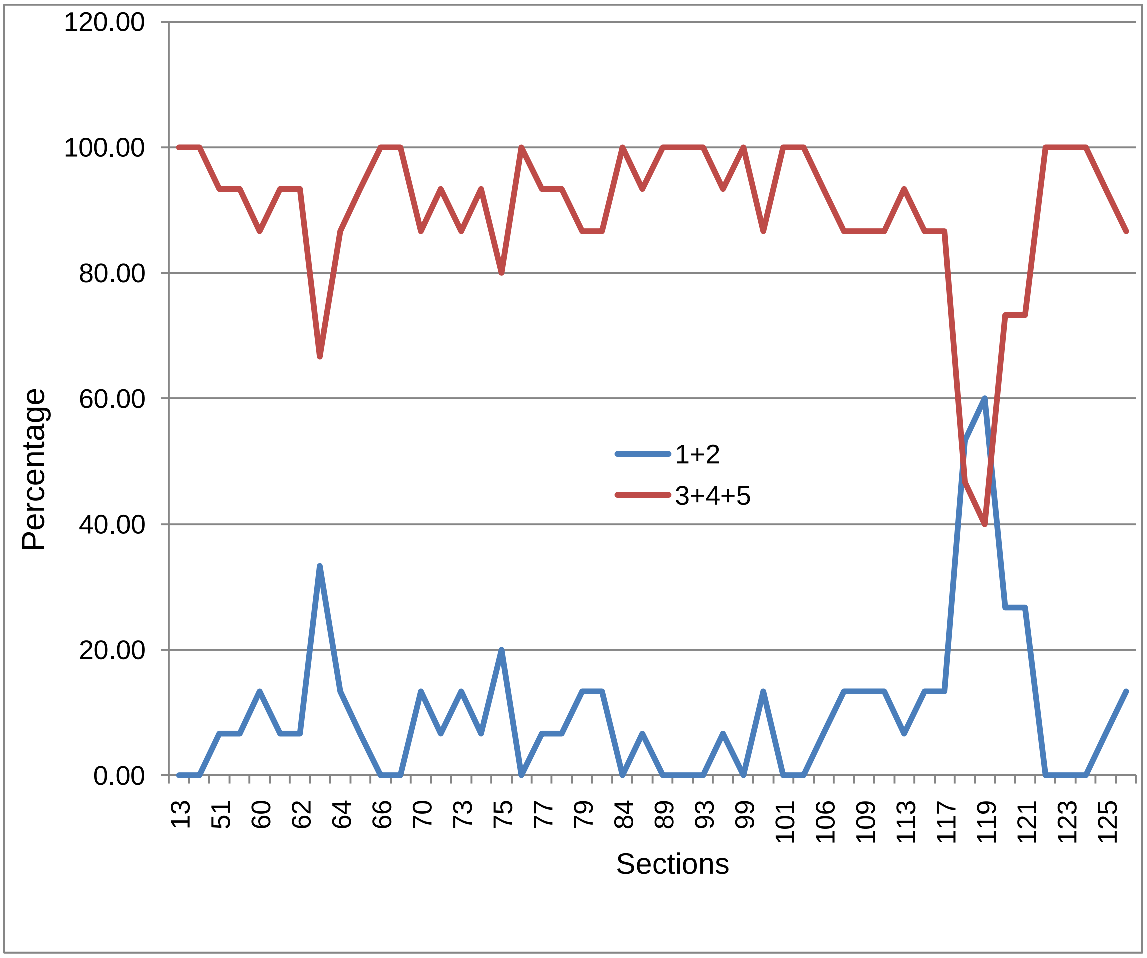


Figure 5.4 – Result of Group B requirements for the OPRTSS

Even conservatively if we drop response 3 from the total, the result for Group A sections and Group B sections does not change significantly (see Figures 5.5 and 5.6)

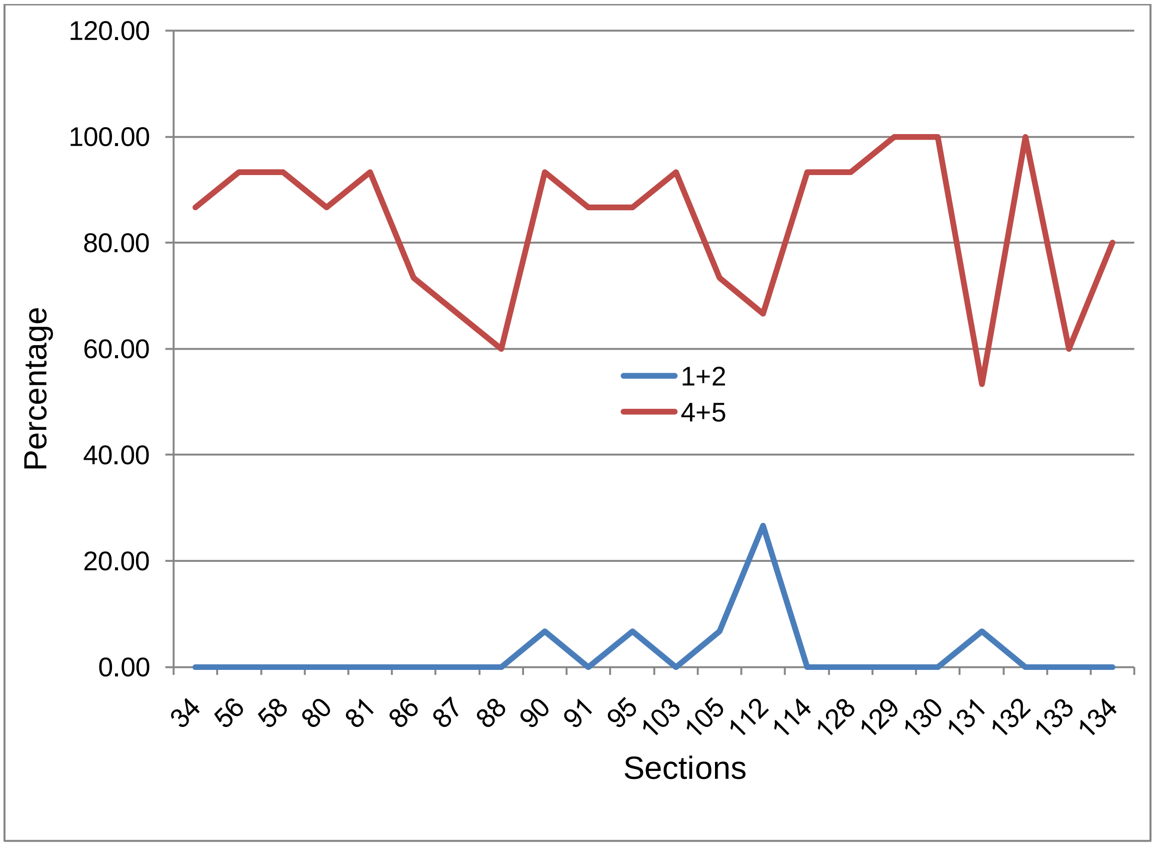


Figure 5.5 – Result of Group A requirements for the OPRTSS

Still, all sections had an impact of 60% or more on structural performance. This clearly proves that the Group A items had a great impact on the structural performance of a project.

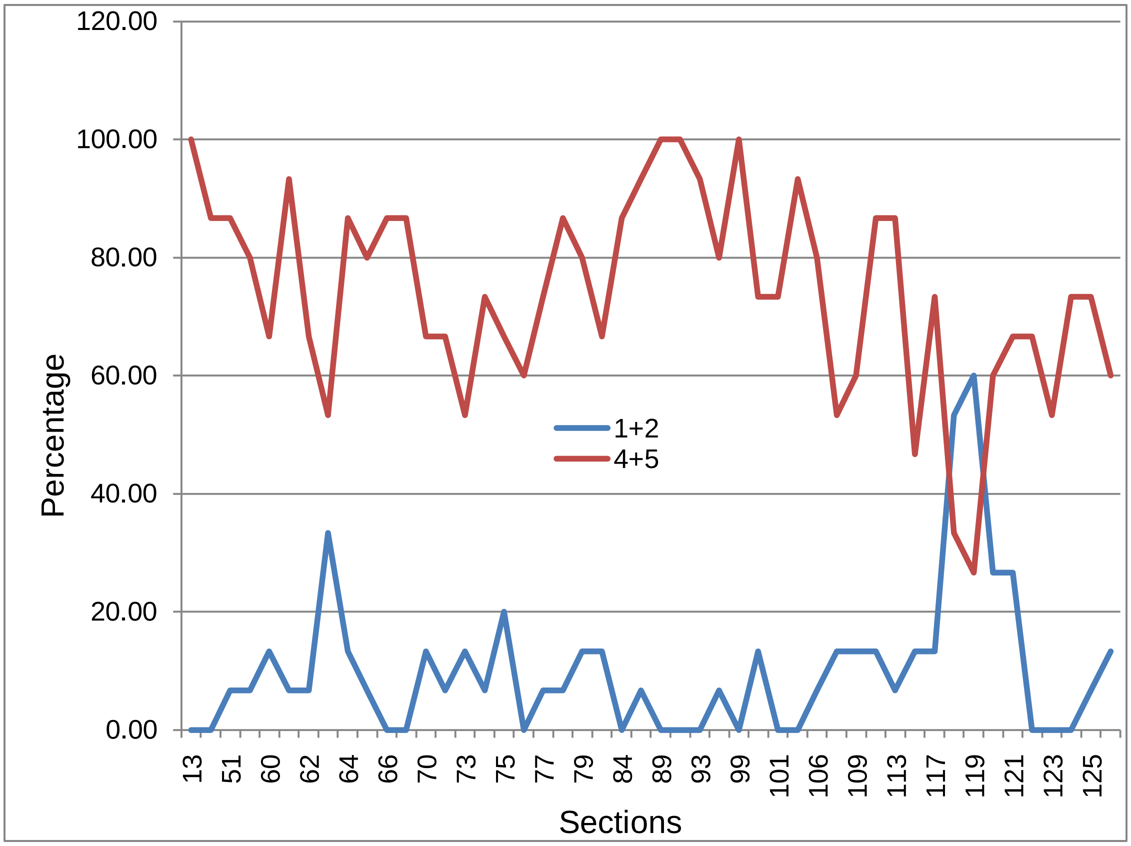


Figure 5.6 – Result of Group B requirements for the OPR

Most sections in this group had an impact of 58% or more. This clearly proves that the Group B items have a great impact on the structural performance of a project.

But when we drop response 3 for the Guideline 0-2005's totals there are more sections that will be more case related than the Groups A and B. (see Figure 5.7).

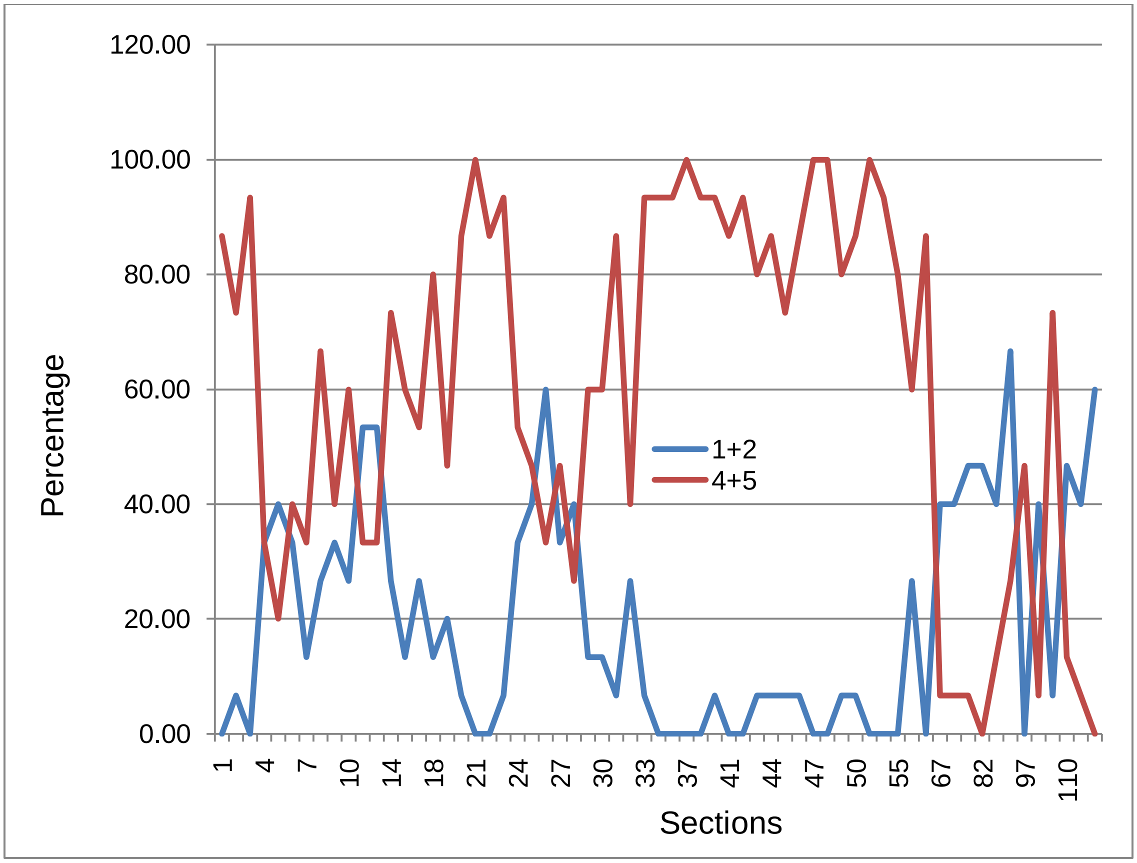


Figure 5.7 – Result of Guideline 0-2005 requirements for the OPRTSS

If we compare this result and the result in Figure 5.2, there are still significant items that have great impact on the structural performance of a project. Putting aside the requirement for delivery services, LEED requirement for building materials and energy conservation for sustainability, all other sections have a high impact on structural performance.

These results were used to create the final OPRTSS. The final OPRTSS was mailed back to the respondents and all respondents agreed to the inclusiveness of these sections in the final OPRTSS.

CHAPTER 6

FRAMEWORK DEVELOPMENT FOR OWNER'S PROJECT REQUIREMENTS FOR TOTAL STRUCTURAL SYSTEMS (OPRTSS)

6.1. Purpose

This Chapter provides information and examples about the structure and contents of the Owner's Project Requirements for Structural Systems as they apply to buildings with concrete and steel frames. Sections are developed using the recommendation of Guideline 0-2005, then additional sections were developed using the results of this research and are shown in *italic* fonts.

6.2. Structural Systems Framework for Owner's Project Requirements

This section provides Owner's Project Requirements for Total Structural Systems (OPRTSS) for structural commissioning of multi-story concrete and steel frame structures that shall be completed by Owners (it is very critical when using this OPRTSS that requirements be completed in a manner that is **measurable and verifiable**.) to: (1) assist owners and commissioning providers to identify and establish a proper task outline for the structural system, (2) identify Structural Engineer's responsibilities and expected performance, and (3) guide Structural Engineer's design teams to the owner's desired final product.

Building Objectives:

List the objectives that are unique to the structural system and that expand upon the objectives and goals described in Whole Building Commissioning.

Site Description and Requirements

List criteria that have a major influence on the Structural development of the building design. Coordinate with Site/Civil.

Neighborhood / Context

Describe the influence of the project site, neighborhood and context.

Existing Buildings

Describe existing buildings and their influence on the design.

Master Plan

Describe existing or in progress master planning issues which affect the design.

Circulation / Access

Describe the opportunities and constraints imposed by circulation issues and required access, including:

- Major Building Access:
- Secondary Building Access:
- Deliveries and Services:

- Trash Docks and Compactors.
- Kitchen, Cafeteria or other food service deliveries and services.
- Lab, Animal or other special deliveries and services.
- Ambulance or Emergency service.
- Fire truck path on elevated structures.

Zoning

Describe the allowable building footprint, maximum height, FAR, and other zoning issues that affect the design. Coordinate with the Site/Civil section.

- Buildable Dimensions and Area:
- Maximum FAR:
- Maximum Height:
- Upper Level Setbacks:

Zoning or Planned Unit Development Restrictions on Materials or design

Describe any special restrictions on the design of the building, such as exterior materials, roof shapes, percent glazed area, etc.

Local, Neighborhood or Community Review Boards or Approvals

Describe any special approvals of the building design that may be required.

Building Code

Authority Having Jurisdiction and Codes in Affect

City of (insert city name)

International Building Code with Amendments (insert year and amendments)

Construction Types

Describe building type (insert building type)

Structural fire rating and protection

Special conditions (insert here)

Sustainability

Describe the Owner's and Design Professional's criteria for sustainability for the project. Describe any specific programs or measuring tools that may be required to measure energy conservation issues such as LEED ratings.

- Energy Conservation
- Life Cycle Costing
- Recycled Materials

Existing Facilities

Identify special criteria for renovations, restorations, additions, alterations or any other work on an existing facility. Coordinate this overall section with the "Existing" paragraphs in the remainder of the OPR. Coordinate with the code analysis and life safety section. Note that building code, energy conservation and accessibility requirements may affect areas of the building beyond the Owner's identified scope. Note that any change of use or occupancy frequently triggers additional code requirements. Adding conference rooms or cafeterias to existing office buildings is a commonly missed change of use.

Program

Functional Criteria

Describe needs for building functions and arrangements of major areas and use such as storage, lobby, corridor, assembly room, special function, etc. If separate Criteria or Program Reports are included, give a basic list of program requirements here.

- Primary Functions
- Support Functions

Structural Criteria

Loads and Serviceability Criteria Standards

American Society of Civil Engineers, "Minimum Design Loads for Buildings and Other Structures" (ASCE 7). General Services Administration (GSA) "Facilities Standards for the Public Buildings Service - Metric Version" PBS-PQ100.1.

Progressive Collapse

Identify need for progressive collapse analysis. Progressive collapse will be analyzed in accordance with Progressive Collapse Analysis and Design Guidelines for New Federal Office Buildings and Major Modernization Projects.

Enclosure Loads

Soil and Foundation Loads

Identify the following:

a) Applicable bearing loads of soils and rock from geotechnical report.

b) Loads applied to enclosure from soil and ground water.

c) Specify type of foundation for the structures.

d) Specify frost penetration.

Roof Live Loads

Minimum live load shall be (Shall be entered by Owners). Roof live loads [will] [will not] be reduced per code.

Service Load Paths - Specific areas will be identified and designed for appropriate loadings to allow for movement of mechanical equipment components across the roof if required. The values of the loads will be based upon the type of equipment to be moved as identified when the building program is detailed.

Roof Ponding Loads

Roofs will be designed for the weight of ponded water considering all primary drainage is blocked. The depth of ponded water shall include the deflection of the roof structure and the distance above the scupper base as required facilitating flow. The height of flow will be based on the serviced area of the roof, the appropriate volume of rainwater and the size of the scupper.

Snow Loads

The ground snow load (pg) established by Code for the Project site is (Shall be entered by Owners).

Importance factor (Is) of (Shall be entered by Owners) in calculating the snow loads.

Exposure factor (Ce): (Shall be entered by Owners) in calculating the snow loads based on a (Shall be entered by Owners) exposure category (Shall be entered by Owners).

Thermal factor (Ct): (Shall be entered by Owners) in calculating the snow loads based on (Shall be entered by Owners).

Calculated “flat roof” snow load (psf): (Shall be entered by Owners).

Snow Drifting – Adjacent to vertical projections, such as parapets, changes in roof elevation, etc., the snow load will be increased above the “flat roof” value in conformance with Code established parameters. Specific snowdrift values will be determined after development of the final roof configuration.

Wind Loads

The Basic Wind Speed established by Code for the project site is (Shall be entered by Owners).

Importance factor: [Increase] [decrease] the wind load based on an importance factor of (Shall be entered by Owners).

Exposure category: Exposure (Shall be entered by Owners).

Specify the following:

a) Design structure as an enclosed or open structure

b) Window requirement for wind prone area

Seismic Loads

Identify Seismic Performance Category and the Components Performance Criteria factor.

Identify site classification and soil type.

Flood loads

Specify flood requirement per Section 1612 of the International Building Code (IBC).

Other special loads

Specify any other special loading required by future tenant use and equipments.

Some General requirement with consideration for other common difficulties in the construction process.

Strength

Specify all material strengths used in the project.

Serviceability

a) Deflection

Structural elements will be designed within the deflection control limits below except where the material codes require more restrictive criteria.

Table 6.1 - Deflection criteria

Framing Element	***Loading***	***Control Criteria****	***Owners additional requirement***
Floor Member	*Live + Dead Load*	*Span/240*	(Shall be entered by Owners)
Floor Member	*Live Load*	*Span/360*	(Shall be entered by Owners)
Floor Member Supporting Glass	*Superimposed Load*	*Span/480*	(Shall be entered by Owners)
Floor Member Supporting Masonry	*Superimposed Load*	*Span/600*	(Shall be entered by Owners)
Typical Roof Member	*Live + Dead Load*	*Span/180*	(Shall be entered by Owners)
Typical Room Member	*Live Load*	*Span/240*	(Shall be entered by Owners)
Elevator Supports	*Live Load*	*Span/1666*	(Shall be entered by Owners)
Sunscreens & Canopies	*Live Load*	*Span/175*	(Shall be entered by Owners)

***** *Modify per additional requirement. See Section 3.3.2*

b) Drift

Inter-story (between any two floors) and total drift control limits: Height/ (Shall be entered by Owners).

Drift due to seismic loads: (Shall be entered by Owners).

Analysis

Overall Structural plans

Specify the following:

a) *Specify requirement for the use of Building Information Modeling (BIM)*
b) *Coordinate all dimensions with Architectural plans*
c) *Provide additional dimensional plans for all vertical supporting systems.*

Grading, excavation and site work.

Specify that a final grading plan must be prepared by the Civil Engineer of record and the plan must be signed by the Architect and Structural Engineer of record to state that they have covered:

a) *Location of foundation steps.*
b) *Specified top elevation of all foundation elements, such as footings, plies, caissons, etc.*
c) *Location and details for all utility pipes, etc. thru structure.*

Specify the responsible party for the design and detail of all site walls and site structures, such as retaining walls, detention or retention vaults, underground storage tanks, etc.

Specify LEED requirement for materials used.

Foundation

Specify the following:

a) *Specify the type of foundation used for each part of the project*.

b) Specify LEED requirements for materials used.

c) Specify requirements for vertical and horizontal expansion joints in foundation walls.

Slab on grade

Specify the following:

a) Slab sub-grade requirements.

b) Specify LEED requirements for materials used.

c) Waterproof membrane.

d) Control/Construction joint spacing

e) Slopes for drainage and other consideration.

f) Requirement for steps.

Vertical Load Resisting System

Specify the following:

a) Type of material

b) Location with proper dimensional information

c) Fire protection

d) Desired vibration control

e) Future use consideration

f) LEED requirement for materials

g) Coordination with all utility systems

h) Consideration for future expansion

Floor System

Specify the following:

a) Floor type

b) Floor finishes

c) Flatness

d) Levelness

e) Top of structure elevations

f) Desired deflection

g) Desired slope, steps and flatness

h) Desired vibration control

i) Coordination with utility systems and other consultants for openings in floors

j) Consideration for future use

k) LEED requirement for materials

l) Consideration for future expansion

m) Insulation

Roof System

Specify the following:

a) Roof type and material type

b) Roof drain and slopes

c) *Top of structure elevations*

d) *Utility systems location and specification and supports.*

e) *Window washing supports*

f) *Coordination with utility systems and other consultants for openings in roof*

g) *Consideration for future expansion*

h) LEED requirement for materials

Exterior curtain walls

Specify the following

a) *Wall finishes and requested limit on movement and deflection*

b) *Party responsible for design and detailing*

c) *Specify require horizontal and vertical expansion/control joints*

d) *Party in charge of design and detailing of roof screens*

e) *Exterior door and window requirements in wind prone area*

f) LEED requirement for materials

Lateral Load Resisting System

Specify the following

a) Any required special inspection for buildings of over 75 feet in height and buildings located in seismic category 'E' and occupancy category of I and II over two stories in height (Section 1709 of IBC)

b) Fire protection

c) *Floor diaphragm connections*

d) *Consideration for future use*

e) LEED requirement for materials

Construction Document issues

Specify the following

a) *Party responsible for design of underground utility system structures.*

b) *Party responsible for design of site retaining walls*

c) *Party in charge of site paving*

d) *Party responsible for design of project signs*

e) *Party responsible for design of Architectural ornaments and canopies.*

f) *Parties responsible for the design of prefabricated items and party responsible for their connections to main structure*

g) *Party responsible for embedded plate coordination*

h) *Party responsible for the design of stairs, handrails guardrails, elevator machine rooms, elevator guide rails, and elevators lateral support system*

i) *Party responsible for design and detailing of barrier cable system and their connections*

j) LEED requirement for materials

Owner's construction/design issues

Deflection

Specify any additional requirement for limiting structural deflection

Flatness/Levelness

Specify any additional requirements for structural finishes.

Future expansion

Specify if structural elements need to be considered for any additional loads due to any future expansion.

Vibration

Specify any additional requirement for limiting structural vibration

Noise Transmission

Specify any additional requirement for limiting structural behavior causing noise transmission.

Progressive collapse

Specify if structural elements need to be considered for any additional loads due to prevention of progressive collapse.

Coordination

Coordinate structural systems with the following systems:

- *Underground Utility Systems Structures*
- *Plumbing System (Guideline 7)*
- *Mechanical Systems (Guideline 1)*
- *Electrical Systems (Guideline 9)*
- *Security Systems (Guideline 11)*
- *Elevator System (Guideline 6)*

- *Fire Protection (Guideline 10)*
- *Exterior Envelope (Guideline 3)*

Operation and Maintenance.

Specify the following:

a) *Items to be inspected during the life of structure.*

b) *Inspection intervals.*

c) *Maintenance requirement of exposed structures to the environment.*

d) *Structure protection for wear and tear.*

CHAPTER 7

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS FOR FUTURE RESEARCH

7.1. Purpose

This chapter provides a summary of the steps taken in this study, as well as research conclusions. A discussion of the methodology used in this investigation and its merits will also be provided. At the end, some areas of inquiry to pursue on the findings of this research will be recommended.

7.2. Summary

The practice of Total Building Commissioning has gained a lot of attention in recent years. Owners and managers are requiring implementation of commissioning in construction projects to ensure the proper performance of the facility on a daily basis, as well as the quality of the building systems throughout the life cycle of the facility.

In today's market, Architects and Engineers must satisfy the demands of Owners who are under intense competition to increase their occupancy and satisfy tenants. Due to an increase in both project and building complexity, construction problems are rising.

These problems are also exacerbated by a lack of proper communication between the Owners, Architects and other design team members responsible for preparing final construction documents that meet Owner's Project Requirements (OPR). This lack of communication is often due to improper design or not having a clear objective by the design team regarding what the Owner's Project Requirements are before construction begins. The structural system of any project is one of the most essential parts of the construction process, thus the development of the structural system was imperative.

The review of the practice of Building Commissioning and Total Building Commissioning and the evolution of these concepts over the past 30 years shows how this practice has emerged to a quality assurance tool. ASHRAE Guideline 0-2005 is the first developed Guideline of the Total Building Commissioning and is the major source for defining the process of Total Building Commissioning. Establishing a well developed OPR for the structural system will be a tool to avoid problems outlined in the last paragraph.

To establish a framework for the structural system, ASHRAE Guideline 0-2005, NIBS Guideline 3-2006, and ASHRAE Guideline 1-2007 were reviewed to identify the critical issues involved. A base of OPR for structural systems was prepared. To complete the OPR and address issues that are not covered in Guideline 0-2005, the researcher visited construction project sites, interviewed practitioners and reviewed multiple documents in Structural Engineering firms. He reviewed past and current litigation regarding structural issues in the construction process of seven projects involving two law firms. These investigations and interviews identified the construction/design issues impacting the structural performance of a project in the construction industry. The identified construction/design issues in this research were divided into three separate groups as follows:

- Group one of construction/design issues was identified in this research as those items that were over and beyond the requirements of applicable building code or engineering principles, but were demanded by the owners due to today's working environment, new technologies and market demands.
- Group two of construction/design issues was identified in this research as those items that were not clearly identified in the construction documents or project contracts. In those issues, there was some ambiguity as to who the responsible party would be to fulfill those tasks. With the knowledge of the experts these construction/design issues were analyzed, defined and added to the OPRTSS for the owners to identify these construction/design issues in advance.
- Group three of construction/design issues was identified in this research as those items that are related to design and construction quality. These construction/design issues were added to this research as a part of OPRTSS to help construction teams address these construction/design issues during document preparation and during construction.

These construction/design issues were quantified and measured with graphs and tables and the framework of the OPRTSS was prepared for the most critical construction/design issues. A questionnaire was designed and sent to the panel of experts to use their knowledge to validate the suggested OPRTSS. The answered questionnaires were analyzed and the suggested OPRTSS was modified to create the final OPRTSS. The final OPRTSS was sent to the panel of experts for their verification and validation to certify the inclusiveness of the final OPRTSS following the directions of the Delphi technique. An overview of research methodology is shown in the following page in Figure 7.1. Boxes with capital letters represent the criteria used for the next research activity box.

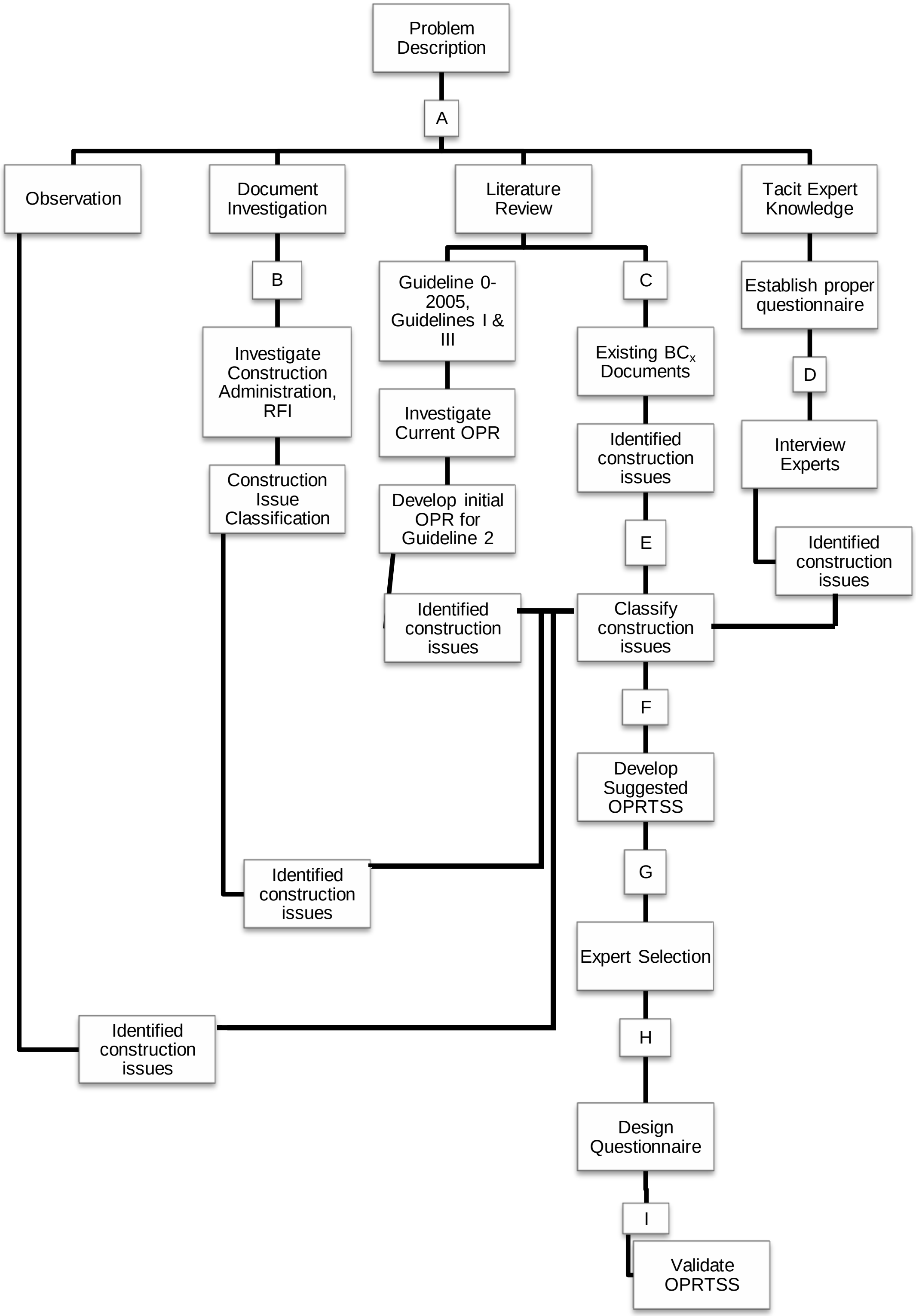


Figure 7.1 Research summary

The following part describes each of the boxes (research criteria) shown in figure 7.1:

A. Using Qualitative Methodology

B. Construction/design issues

C. Established G.L. & Their OPR

D. Select Panel of Experts with desired qualifications

E. Separating construction/design issues on their role in effecting construction process

F. Selecting issues that can be omitted during construction process using OPR

G. Using licensed professional structural engineers for their expertise in the construction of structural system

H. Validating entire OPRTSS for content

I. Recording & eliminating certain issues with expert approval

7.3. Research conclusions:

The research identified performance indicators that impact structural performance of a project. These indicators showed impact during the delivery of concrete or steel framed projects. There were issues not defined or required by contracts, which were over and beyond the requirements of applicable building codes or engineering principles. These issues needed to be defined during the pre-design stage. The panel of experts rated the impact of these indicators as having high to extreme impact on the structural performance of the project. These items, if not addressed and considered, will have a negative impact on the success of the project and will cause occupancy problems for the Owners.

The development and investigation of the initial OPR recommended by ASHRAE Guideline 0-2005, ASHRAE Guideline 1-2007 and NIBS Guideline 3-2006 was found to be inadequate for the total structural system. Therefore, this research was required to identify other construction/design issues impacting the structural performance of a project.

The following important construction/design issues were identified through construction field observations by construction professionals as causing delays and future expense if not addresses and considered by the Owners in the pre-design stage of projects:

1) Top elevation of foundation elements.
2) Location and details for all underground utility.
3) Requirements for vertical and horizontal expansion joints in foundation walls.
4) Location and requirements of construction joints in slab on grade.

The following important performance indicators that impact structural performance over and beyond the requirements of applicable building codes and engineering principles were identified during interviews with experts on the specific subjects. The experts agreed that these items should be considered by Owners at the pre-design stage of projects:

1) Structure vertical and horizontal deflections.

2) Structural vibration due to structural performance.

3) Noise transmission due to structural performance.

4) Levelness and flatness of structural finishes.

5) Effects of future expansions on structural performance.

6) Requirements for prevention of progressive collapse.

7) Structural maintenance.

8) Structural coordination with all other systems.

The following important construction/design issues were identified through the contract administration investigation process as impacting structural performance. These issues were creating ambiguity in the responsibilities of the structural engineer and causing false expectations from and of the structural engineers. These issues should be addressed by the Owners during the pre-design stage of projects:

1) Party responsible for design of underground utility system structures.

2) Party responsible for design of site retaining walls

3) Party in charge of site paving

4) Party responsible for design of project signs

5) Party responsible for design of Architectural ornaments and canopies.

6) Parties responsible for the design of prefabricated items and party responsible for their connections to main structure

7) Party responsible for embedded plate coordination

8) Party responsible for the design of stairs, handrails guardrails, elevator machine rooms, elevator guide rails, and elevators lateral support system.

9) Party responsible for design and detailing of barrier cable system and their connections.

10) Window requirement for wind prone area.

11) Dimensional coordination between Architectural and Structural drawings.

12) Additional dimensional plan for all vertical supporting elements.

13) Additional dimensional plan for all floor, roof and wall openings for utility purposes.

14) Responsible party for the design of curtain walls.

15) Top elevation of structural steel elements.

16) Structural support for window washing elements.

17) Responsible party for the design of roof screens.

18) Structural fire protection.

19) Roof and floor diaphragm connections.

The research concluded that the construction/design issues identified in site observations, personal interviews of experts, the questionnaire responses from the panel of experts and the investigation of contract documents added to the initial OPR to create the suggested Framework for OPRTSS all had a moderate to extreme impact (scales of 3 to 5) on structural performance.

The results of the questionnaire and the responses of the panel of experts provide sufficient evidence for verification of the research hypothesis. The existence of construction and design issues in the construction process has to be identified and addressed by the Owners to prevent delays, confusions and litigation.

Strong evidence was found that an established Owner's Project Requirements for the Total Structural Systems (OPRTSS) of Total Building Commissioning can assist Owners, commissioning authorities and Structural Engineers to achieve results that will meet market requirements for their projects.

A well defined OPRTSS is expected to reduce construction delays, confusion in the construction process and construction litigations. The OPRTSS will maximize a Structural Engineer's ability to prepare construction documents in a timely manner and enable him to price projects competitively.

7.4. Recommendation for future research:

The developed Framework for OPRTSS in this research was focused on concrete and steel framed structures. This Framework (after adoption into Guideline 2) can be used and implemented in structural commissioning of this type of structure. It is recommended that commissioning be investigated in future research and be implemented in the Framework of other types of building materials.

The Development of Framework for acceptable testing requirements for structural systems, as well as training procedures for Owners, is a suitable research topic.

As Structural Commissioning expands, other annexes for Guideline 2 should also be developed for a comprehensive Guideline. Some of the more important annexes in Guideline 2 for future research could be the Commissioning Process, the Cost and Benefit of the Commissioning Process, the various Roles and Responsibilities of Commissioning, and the Commissioning Plan and Basis of Design.

Another area of future research might be establishing an OPR for other structural systems such as: Masonry Construction, Wood Construction and Light Gauge Construction.

It is believed that there are twelve or more Guidelines under Total Building Commissioning (TBC_X) that are either currently developed, being developed, in an initial stage of development or expected to be developed in future. Development of other Guidelines for other systems and their annexes is a suitable research topic.

APPENDIX A

OVERVIEW OF THE DELPHI TECHNIQUE

This Appendix provides a detailed discussion of several methodologies. The discussion will begin with an overview on the validity of group judgment over individual judgment and the underlying theories behind this concept. Common group techniques will be reviewed, including the Delphi method, which will be discussed in greater detail. Delphi is the primary methodology used in this research. This section will end with a summary of the concerns involved with implementing the Delphi methodology.

The source articles and publications used for this discussion were identified through a review of existing literature. The first step of the literature survey included a search of several databases, including *EBSCO-Host* and *Pro-Quest*. Preliminary results identified the peer-reviewed journal, *Technological Forecasting and Social Change*, as the major source of Delphi publications. Most of the related articles were then identified through this journal. In addition, citations from these articles were used to find additional articles related to this subject.

Group vs. Individual Judgments

Before beginning a discussion of the concept of group judgment, it is important to make a clear distinction between the term *Judgment,* and two other states of awareness, *Knowledge* and *Guess*. Sniezek and Henry (1989) define these three concepts based on differing levels of certainty. In this view, a Judgment task can be defined as the association of “some level of uncertainty” with the “accuracy of response,” as opposed to a Knowledge task, which is a result of “perfect certainty” about the “accuracy of response,” or a Guess, which is basically a response with “no certainty” (Sniezek, 1989).

The use of groups to make decisions and judgments has been an essential part of the modern era. Juries, councils, committees, task forces and boards are all based on the widespread belief that N+1 heads are better than one (Hill, 1982). The underlying assumption is that the combination of individuals in a group setting brings different perspectives together and provides a larger knowledge source for decision-making. Therefore, the group can produce more-accurate judgments and better solutions. This assumption is so strong that it has been at the foundation of all the decision-making systems of modern society.

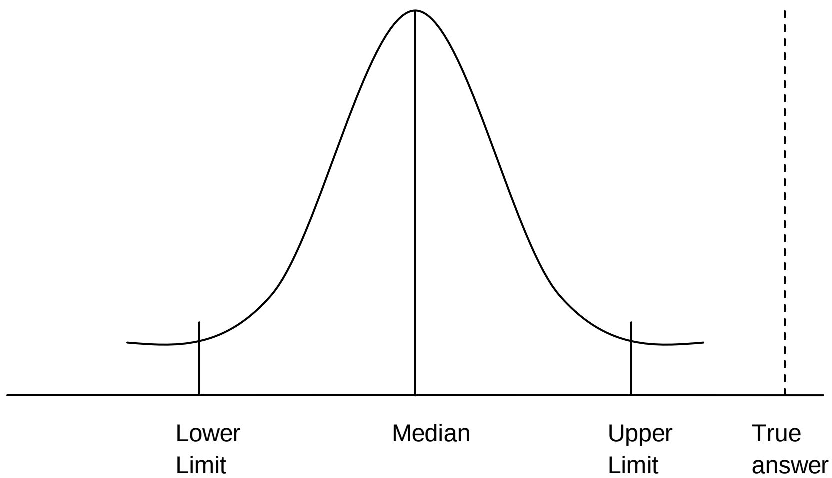
However, it wasn’t until the second half of the twentieth century that this assumption was tested based on scientific methodologies. Since the late 1940s and 1950s, numerous studies have focused on comparing the true performance of groups and individuals, in regard to decision-making tasks. The results have not been surprising. A number of studies provide evidence that committees or groups have an advantage over individual judgments in a variety of domains (Hill, 1982) (Nisbett, 1980) (Rowe G. W., 1991). Studies also showed that even a simple aggregation of individual judgments is more accurate than the judgment of a random individual (Woudenberg, 1991). The superior ability of groups over individuals in accurate decision-making can be explained based on the “theory of errors” (Dalkey N. C., Toward a theory of group estimation." The Delphi Method: Techniques and Applications, 1975). According to this theory, the median response of a group will always be at least as close to the true answer as one-half of the individuals in the group (Figure A.1a). In addition, if the group response range includes the true answer, the median group response will be more accurate than more than half of the group (Figure A.1b). As shown in the Figures, in both cases, there is always a group member whose response will be nearest to the true answer than the group mean. Empirical findings have confirmed this matter, showing the group performance to be superior to the performance of the best individual (Davis, 1969) (Hill, 1982). However, it should be noted that groups are virtually always used in situations where no prior knowledge of the true answer exists. In such cases, identification of the best individual whose response is the closest to the true answer is impossible, and therefore, the group response becomes more accurate.

Group Techniques

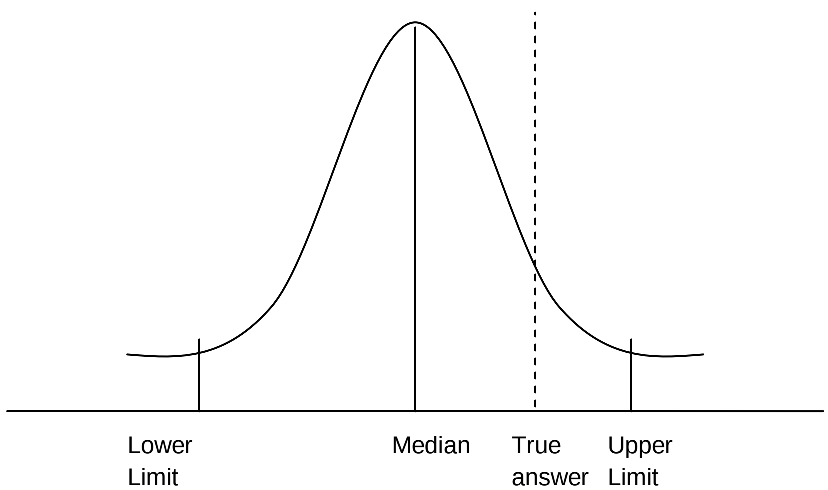
Staticized Groups

The simplest form of obtaining a group judgment is through the use of *Staticized Groups* (Rowe G. W., 1991). This method is basically a polling technique in which the opinions of a group of individuals are gathered separately and summarized, based on common statistical methods, to form the group decision. Members of a staticized group are usually selected randomly to form a statistical sample of the target population.

Due to their simplicity and convenience of use, staticized groups have been very popular, and they have been employed in a number of domains. Opinion surveys are good examples of staticized groups. Although studies have shown that staticized groups can produce better results than individuals, use of this group technique has been largely criticized. The main criticism is that, based on their nature, staticized groups don't provide an opportunity for interaction among individuals. At the same time, a great body of research shows that interaction among a set of individuals has some usefulness, and can produce better results in the construction of subjective judgments (Armstrong, 1978).



A: The group median is more accurate than half of the group



B: The range of estimates contains the true answer. The group estimate is more accurate than a majority of the group

Figure A.1 – 'Theory of Errors' in Explaining Superiority of Groups Response over Individuals' (Dalkey N. C., Toward a theory of group estimation." The Delphi Method: Techniques and Applications,, 1975)

Interacting Groups

Interacting Groups are the most common group technique. In this method, individuals are brought together to form a refined opinion after deliberate discussions (Rowe G. W., 1991). Studies have shown that judgments from interacting groups are more accurate than a statistically aggregated judgment (Woudenberg, 1991). This can be explained based on the increased knowledge sources available to each group member, which equals at least the sum of information available to any particular individual within that set (Rowe G. W., 1991). In addition, it has been argued that being part of a group can have other advantages that will result in better performance, such as increased commitment of individuals, assistance in resolving ambiguous and conflicting knowledge and facilitation of creativity (Lock, 1987).

However, interacting groups are not without pitfalls. Lock (1987) summarizes the downsides of the group process into three categories:

- <u>Groupthink:</u> This is the result of group members' access to the same knowledge base. Groupthink emerges as a restriction on the range of ideas generated by a group. Groupthink can also be a result of an individual's desire to conform to group norms.
- <u>Inhibition of contributions:</u> This is caused by differences in the status of individuals. Most individuals are not willing to put forward ideas that are contrary to the ideas that have already been expressed in the group. Inhibition may also be caused by the presence of one dominant individual in the group.

- <u>Premature Closure:</u> This results from the tendency to adopt the first alternative, which is satisfactory to all group members, rather than reaching the best alternative.

These and other additional factors, such as an individual group member's desire to "win" or avoid changing a position once they've taken it in front of the group, cause interacting groups to not perform up to their optimal level and potential (Rowe G. W., 1991). As a result, several other alternatives to interacting groups have been proposed. These alternatives attempt to reduce or totally eliminate the shortcomings of interacting groups, by changing the unstructured interaction among group members to a more structured process of feedback. In the following section, two main structured techniques (Nominal Group Techniques (NGT) and Delphi) are discussed.

Nominal Group Technique (NGT)

The *Nominal Group Technique* (NGT) is the most widely known structured group technique that provides direct interaction among individuals (Woudenberg, 1991). NGT was developed by Andre L Delbecq and Andrew H. Van de Ven in 1968, as a result of their social-psychological studies in a number of different fields. These fields included industrial engineering, studies of NASA program design problems and studies of citizen participation in program-planning (Delbecq, 1975); (Van_De_Ven, 1974).

An NGT study starts with individuals seated around table writing on a pad of paper their ideas related to a problem which has been given to them. Each individual presents one of his ideas to the group. The ideas are recorded and discussion does not start until each person has verbalized his ideas.

After all ideas are presented, the group begins to discuss them one-by-one. After the discussion, each individual writes down his/her own evaluation of the ideas separately. The final stage is to aggregate all the individual evaluations to arrive at a group decision. NGT attempts to eliminate some of the negative aspects of interacting groups by separating the processes of independent idea generation, structured feedback and evaluation and aggregation of opinions (Lock, 1987).

Delphi Technique

Delphi Technique is a structured process which utilizes a series of questionnaires or rounds to gather and to provide information (Keeney, 2001). A Delphi can be seen as a virtual group meeting, which aims to make use of the positive aspects of interacting groups, while removing the negative aspects largely attributed to the social difficulties within such groups (Okoli, 2004); (Rowe G. W., 1991).

The Delphi Technique was developed by Dalkey and Kaplan and their associates at the RAND Corporation (Van_De_Ven, 1974). Kaplan headed a research effort directed at improving the use of expert predictions in policy-making (Dalkey N. C., 1968). He found that unstructured, direct interaction did not provide more-accurate predictions than an aggregation of individual predictions (Kaplan A. A., 1949); (Woudenberg, 1991). Kaplan associated this low performance with the negative aspects of face-to-face meetings and developed Delphi as a way to reduce these negative aspects. Kaplan coined the name "Delphi" after the site of the ancient Greek oracle at Delphi where necromancers foretold the future (Dalkey N. C., 1968); (Gordon, 1994). (Dalkey N. C., 1963) Described Delphi as a procedure to *"obtain the most reliable consensus of opinion of a group of experts… by a series of intensive questionnaires interspersed with controlled opinion feedback."* In a Delphi study, the participants are asked individually, through a questionnaire, to provide their estimates for a variable in question. Then, the feedback is collected and summarized in a way to conceal the origin of original estimates. The results are then circulated and participants are asked if they wish to refine their previous answers based on the summary results. This iteration process continues until estimates stabilize (Lock, 1987).

A Delphi study has three major characteristics: anonymity; iteration with controlled feedback; and statistical aggregation (Dickey, 1978):

1. Anonymity: In a Delphi study, the identity of respondents stays concealed throughout all the rounds. This anonymity and isolation helps to largely eliminate most of the social pressures to conform that arise in interacting groups, such as domination of a single individual, or avoiding change of a position once one is made (Van_De_Ven, 1974).
2. Iteration with Controlled Feedback: This takes place between different rounds and allows members to review and change their response in light of additional information and opinions provided by other group member (Rowe G. a., 1999).
3. Statistical Aggregation: In the final stage of a Delphi study, the group response is obtained through statistical aggregation of the final individual responses. Statistical techniques may also be used to provide the level of consensus strength (Rowe G. a., 1999).

Like other group techniques, the underlying mechanics of Delphi can be explained based on the “theory of errors,” which was described earlier in this chapter. In addition, Dalkey (1975) hypothesized that a Delphi will have a superior performance to unstructured group techniques as a result of the iteration process. According to Dalkey, the iteration and feedback built into the Delphi process, provides an opportunity for the less-knowledgeable panelists (whom he called “swingers”) to move towards more-accurate panelists (known as “hold outs”) and, therefore, results in a more-accurate response for the whole group (Figure A.2). This is based on the assumption that experts on a subject are less likely to change their response during the iteration and feedback process than people who have less knowledge on the subject. Some empirical evidence has supported this assumption. For example, Rowe and Wright (1996) found that the most-accurate Delphi panelists in the first rounds changed their estimates less frequently over rounds than those who were initially less-accurate.

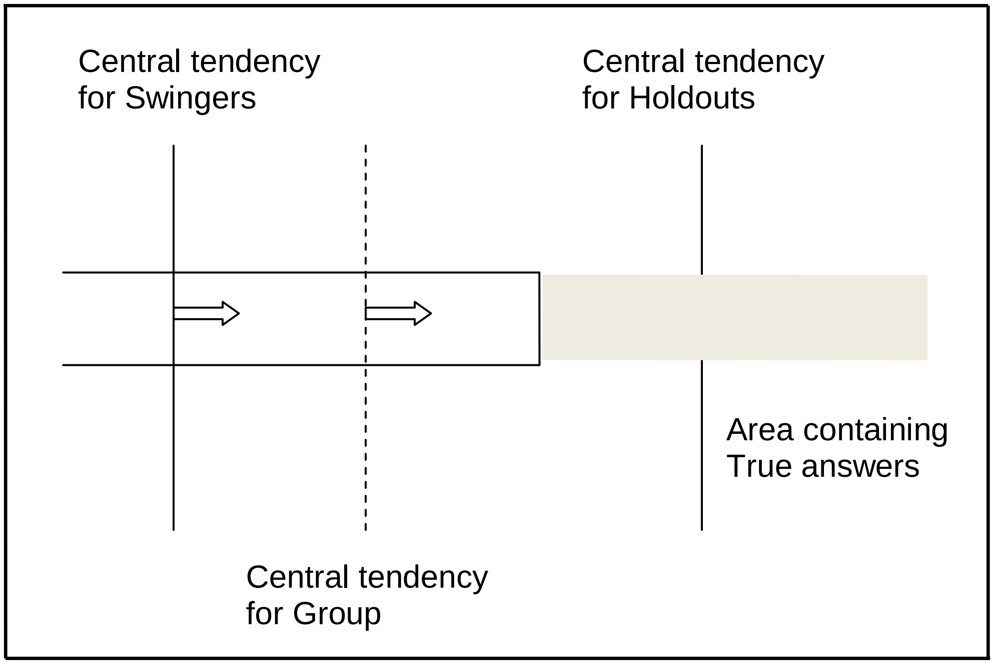


Figure A.2 Shift of Average Group Response during Iteration and Feedback Process (Dalkey N. C., 1975)

Delphi and Inquiry Systems

Inquiry systems (IS) are philosophical systems, which underlie different methods used for analyzing a phenomenon (Lock, 1987). According to Mitroff and Turoff (1975), an inquiry process is compromised of four major steps. First, an individual is faced with some assumed “external event” or “raw data set” which is considered to be a characteristic property of the “real world.” Second, this individual transforms or filters this “raw data” into the “right form,” so it can be inputted into a model. Next, the model transforms the “input data” to “output information.” Finally, this “output information” can be passed to another filter, so it can be used by the “decision-maker.” Mitroff and Turoff describe five main inquiry systems, which can be used as the philosophical basis for the Delphi technique:

- Lockean IS: This states that truth is *experimental*. Based on this inquiry system, the truth of a model is measured in terms of its ability to:
    1) Reduce every complex proposition down to its simplest referents; and,
    2) Ensure the validity of simple referents, by means of widespread, freely obtained agreements between different observers.
- Leibnizian IS: Truth is *analytic*. Based on this IS, the truth of a model is measured in terms of:
    1) Its ability to offer a theoretical explanation of a wide range of general phenomena; and,
    2) Our ability to state clearly the formal conditions under which the model holds.
- Kantian IS: This has a *synthetic* view of the truth. In other words, in a Kantian IS, truth has both empirical and theoretical natures. Truth of a model is measured in terms of the model's ability to:
    1) Associate every theoretical term of the model with some empirical referent; and,
    2) Show how underlying every empirical observation is a theoretical referent.
- Hegelian IS: Truth is *conflictual*. In other words, truth is a result of a complicated process, which depends on the existence of a plan and a counter plan.
- Singerian IS: Truth is *pragmatic*. Truth of a system is relative to the overall goals and objectives of the inquiry, and is measured with respect to its ability to:

1) Define certain objectives;

2) Propose several alternative means for securing these objectives; and,

3) Specify new goals to be accomplished by some future inquiry.

Delphi is a classic example of Lockean IS, since its main purpose is to get consensus from expert judgments (Mitroff, 1975); Parente and Anderson-Parente 1987). However, Mitroff and Turoff argue that some applications of Delphi are based on a different inquiry basis. For example, policy Delphi's, which function as a result of experts debating on mostly unstructured issues, can best be described from a Hegelian viewpoint; or in problems, in which the purpose is to elicit different alternatives, a Kantian Delphi can be more appropriate than pure Lockean or Leibnizian approaches (Mitroff, 1975).

As a result, we can conclude that, for a researcher who is intending to perform a study, knowledge of the inquiry base used in the method is very important. This knowledge is important because it defines the merits and boundaries of the studies and can help identify the limitations of the technique.

Applications

The first application of Delphi was used in 1948 to improve the betting scores at horse races (Woudenberg, 1991). However, the first major application of this method did not occur until the 1950s, when it was used on a U.S. Air Force-sponsored project. The goal of the project was to gather expert opinions on the selection of an optimal U.S. industrial target system, from the point-of-view of a Soviet strategic planner (Rowe G. a., 1999). Application of Delphi during the 1950s, however, was limited to army-sponsored projects in the Rand Corporation. Use of the Delphi technique became popularized in the 1960s, after it was first described in a published article in 1963 (Gupta, Technological Forecasting and Social Change, 1996).

Since its development, one of the major applications of the Delphi has been in technological forecasting. Today, it is estimated that 90% of all technological forecast studies are based on Delphi (Yuxiang, 1990). In addition to forecasting, Delphi has been used extensively for other applications, such as policy formation and decision-making (Rowe G. a., 1999). Currently, Delphi is applied to a number of different problems, such as project evaluation, short and long range forecasting, science and technology planning, policy formulation, energy generation, urban analysis, bank automation, risk management, market research, curriculum development, and others (Gupta, Technological Forecasting and Social Change, 1996). Delphi studies are used in various areas, such as education, business, health care, information systems, engineering and transportation (Rowe G. a., 1999). Interest in Delphi has expanded from non-profit organizations and government to industry and academia (Linstone H. A., 1975).

In the construction industry, Delphi has been applied to a number of professional and academic problems including: development of residential areas (Anatharajan, 1982); bridge condition rating and effects of improvements (Saito, 1991); construction process quality (Arditi, 1999); procurement selection (Chan A. P., 2001); project risk management (Cano, 2002); identifying factors affecting international construction (Gunhan, 2005); and determining the standard of care for structural engineers (Kardon, 2005).

Delphi Critique

Despite its extensive use in both industry and academia, application of Delphi technique has not been without criticism. The first major criticism of the Delphi technique was proposed by Sackman (Sackman, 1974). Referring to a number of studies that were conducted based on the Delphi method; Sackman strongly criticized the use of Delphi to obtain any scientific results. In response, several authors questioned Sackman's findings. Linstone (Linstone H. A., 1978) argued that most of Sackman's criticism is pointed toward poor executions of Delphi, rather than the method itself, and he felt that Sackman had ignored significant supportive evidence. Coates (Coates, 1975) argued that the criteria in evaluating a Delphi is not so much that it is *right*, but that it is *useful*. He states: *"If one believes that the Delphi technique is of value not in the search for public knowledge, but in the search for public wisdom, not in the search for individual data, but in the search for deliberative judgment, one can only conclude that Sackman missed the point."* Furthermore, Mitroff and Turoff (Mitroff, 1975) noted that much of the accusation that the Delphi technique is non-scientific, arises from the misconception in equating what is "scientific" to what is "Leibnizian."

In recent years, as a result of growing application of Delphi, especially in the scientific field, a number of studies have been performed on the validity of this technique. The following is a summary of the Delphi method's major shortcomings, as cited in these studies:

- <u>Accuracy</u>: Accuracy of a Delphi study can be expressed in terms of the correspondence between the obtained group judgment and the true value (Woudenberg, 1991). Since most Delphi studies are on unknown issues, such as forecasting an event in the far future, accuracy of Delphi studies is hard to measure. Strauss and Ziegler (Strauss, 1975) argue that the claim that Delphi represents valid expert opinion is scientifically untenable and overstated. In response, Goodman (Goodman, 1987) argues that, if the panel members in the study are representative of a group or area of knowledge, then content validity can be assumed. In addition, there have been studies that show the result of Delphi have been accurate in terms of forecasting (Ono, 1994). A study by Rowe et al (2004) shows that the accuracy of judgmental probability forecasts increases over several Delphi rounds.

- Reliability: Reliability is defined as the certainty with which an instrument produces the same results over time (Woudenberg, 1991). The Delphi technique has been heavily criticized as having no evidence of reliability; meaning, there is no guarantee that the same results will be obtained if the same Delphi study is repeated with another panel (Keeney, 2001).
- Anonymity: Another criticism of Delphi concerns the issue of anonymity. It has been argued that complete anonymity may lead to lack of accountability, and will encourage ill-considered judgments (Goodman, 1987). It has also been argued that the anonymity of Delphi will hinder the positive effects of unstructured group interactions, such as flexibility and richness of non-verbal communication (Woudenberg, 1991). In addition, Dijk (DIJK, 1990) claims that this anonymity prevents a meaningful discussion from being held.
- Consensus: Consensus resulting from a Delphi study has also been the subject of criticism. Keeney notes that the existence of consensus from a Delphi process does not mean that the correct answer has been found (Keeney, 2001). Also, the Delphi technique has been criticized as a method

which forces consensus (Goodman, 1987). Some study findings suggest that the consensus gained over several rounds may be a result of panelists simply altering their estimates, in order to conform to the group without actually changing their opinion (Rowe G. a., 1999); (Woudenberg, 1991).

Empirical evidence supports this argument by showing that a majority opinion exerts a strong pull on minority opinion, even when the majority favors an incorrect answer (Rowe G. W., 2004). It is also argued that social pressures, such as the impact of a dominant individual, are still felt even though they are not as immediate and threatening as in an unstructured group (Rowe G. W., 1991).

In considering the varying criticism of the Delphi method, it should be emphasized that it is a technique of “last resort,” to be used when no adequate models exist upon which some statistical predictions or judgment might be based (Coates, 1975).

Although criticism of the Delphi method have been countered by studies in the favor of the technique, consideration of its criticism is useful in recognizing this method’s shortcomings as a valid research methodology and in recognizing opportunities for improvement. Therefore, the “Delphi Method” has largely escaped examination (Rowe G. W., 1991). Delphi is not a procedure intended to challenge statistical or model-based procedures, against which human judgment is generally shown to be inferior; rather, it is intended to be used in judgment and forecasting situations in which pure, model-based statistical methods are not practical or possible. This is due to a lack of appropriate data, and, thus, some form of human judgment input is necessary (Rowe G. a., 1999).

The Delphi method is especially effective in difficult areas that can benefit from subjective judgments on a collective basis, but for which there may be no definitive answer (Lindeman, 1975). As Rowe et al. (Rowe G. W., 1991) conclude, Delphi is a valuable technique in judgment-aiding, but improvements are needed.

Delphi vs. Nominal Group Techniques

Delphi and NGT are both well-known structural techniques, and each has its own characteristics. The prime difference between them goes back to the level of anonymity, specifically at the feedback stage. NGT provides an opportunity for direct communication among participants at the feedback stage. Although this direct communication has been cited as an advantage of NGT over Delphi, it also gives NGT the normal drawbacks cited for interactive groups (Lock, 1987).

A number of studies have made an attempt to compare the results of Delphi and NGT group techniques. Most of these studies have compared these two methods on three main dimensions: accuracy of the technique; quantity of the ideas generated and participant satisfaction. The results of studies that have compared the accuracy of Delphi and NGT have not been consistent. Gustafson (Gustafson, 1973) and Miner (Miner, 1979) found NGT to be more accurate than Delphi. On the other hand, Fischer (Fischer, 1981) Boje and Murnigham (Boje, 1982) found the two techniques to be equally accurate. In addition, another study (Erffmeyer, 1984), found Delphi results to have a higher quality (in terms of comparison of rankings to “correct rank”).

As for the quantity of ideas, Van De Ven and Delbecq (Van_De_Ven, 1974), found NGT to produce more ideas than Delphi. At the same time, a study by Hill (1982) showed that NGT and the Delphi procedure did not differ in quantity of unique ideas. In terms of satisfaction of the participants, studies by Van de Ven and Delbecq

(Van_De_Ven, 1974) and Hill (Hill, 1982) showed a higher satisfaction among participants of NGT than Delphi. The first study explained the lower satisfaction with Delphi process as a result of the lack of social-emotional rewards in the problem-solving process and unresolved conflicting or incomplete ideas. At the same time, a more recent study (Hornsby, 1994) showed participants in a Delphi study to have higher satisfaction with the process than NGT. As discussed, the results of comparisons between these two techniques have been very different. This disparity can be explained based on the fact that each study used a different evaluation method, and each study used a different variation of Delphi. These differences may account for the discrepancies.

Based on these contrary findings, it is difficult to draw a conclusion as to which method is superior. Selection of a method can then be based purely on the specific research requirements (i.e. geographical, time, cost, etc.) and the qualitative differences of these two methods. Table A.1 summarizes these qualitative differences based on Van De Ven and Delbecq (Van_De_Ven, 1974).

Based on these differences, Delphi was selected as the appropriate knowledge gathering technique for this study. This technique was chosen due to its ability to provide an environment of discussion among a panel of experts and gain a level of consensus among them, while minimizing the difficulties involved with face-to-face meetings, such as the limited amount of time and availability of experts and geographical considerations.

Delphi also helps to remove the negative impact of face-to-face meetings and keeps the independency of individuals in analyzing the situation.

Table A.1 - Qualitative Differences between Delphi and Nominal Group Technique
(Van De Ven and Delbecq 1974)

Dimension	Nominal Groups	Delphi Technique
Overall Methodology	Structured face- to-face group meeting Low flexibility Low variability in behavior of groups	Structured series of questionnaires & feedback reports Low variability respondent Behavior
Role of orientation of Groups	Balanced focus on social maintenance and task role	Task- instrumental focus
Relative quantity of ideas	Higher: independent writing & hitch-hiking round-robin	High: isolated writing of Ideas
Search Behavior	Proactive search Extended problem focus High task centeredness New social & task Knowledge	Proactive search Controlled problem focus High task centeredness New task knowledge
Normative Behavior	Tolerance for nonconformity through independent search and choice activity	Freedom not to conform through isolated anonymity
Equality of participants	Member equality in search & Choice phases	Respondent equality in pooling of independent judgment

Table A.1 continued

Table A.1 continued

Dimension	Nominal Groups	Delphi Technique
Method of problem-solving	Problem-centered Confrontation and problem Solving	Problem-centered Majority rule of pooled independent judgments
Closure decision process	Lower lack of closure High felt accomplishment	Low lack of closure Medium felt Accomplishment
Resources utilized	Medium administrative time cost preparation High participant time and cost	High administrative
Time to obtain group ideas	1.5 hours	5 calendar months

Delphi Execution

Despite the extended use of the Delphi method over the past four decades, a standard procedure for implementation still does not exist. Delphi studies differ from each other in many ways. In fact, the number of variations of Delphi is almost as many as the number of the Delphi studies that have been conducted. In this section, a more-detailed discussion of the important elements of a Delphi procedure is provided. The goal is to find a more scientific base for implementation of this technique, based on a comprehensive review of the literature relating to this topic.

Unstructured vs. Structured Delphi

In conventional Delphi's, the first round is always unstructured, meaning that the participants are allowed to identify and elaborate on those issues they consider important (Rowe G. a., 1999). However, some recent applications of Delphi have used structured first rounds, in which an inventory is provided to save time and make the process simpler for the monitor and panelists. This information is established by interviewing key experts (Woudenberg, 1991). This is especially useful in an industrial context, in which the experts are technical specialists who may not be aware of all the dynamics of an issue (Parente, 1987).

However, it has been argued that use of a structured first round in a Delphi study will prevent involvement of experts in expressing their beliefs as to what may be important in relation to the issues of interest. Therefore, this may deny the construction of coherent scenarios for assessment (Rowe G. W., 1991). Also, Keeney et al. (Keeney, 2001) argue that providing information in the first round may introduce some bias in the panelists' judgment.

Number of Rounds

One of the main differences between variations of Delphi implementation has been in the number of the rounds (Rowe G. W., 1991)). The original Delphi used by the Rand Corporation consisted of four rounds (Keeney, 2001). However, different Delphi studies have been implemented from as few as 2 to as many as 10 rounds (Woudenberg, 1991).

Selecting the number of rounds in a Delphi study is an important issue, as studies have shown that the accuracy of judgmental probability forecasts increases over Delphi rounds (Rowe G. W., 2004). It has been stated that most of the change in panelists' responses occurs after one or two iterations (Rowe G. a., 1999), and consensus is almost always maximized after the second estimation round (Woudenberg, 1991). Results from the Erffmeyer et al. (Erffmeyer, 1984) study showed that the quality of responses increased up to the fourth round, but not thereafter. By the same token, the issue of time is also of considerable importance, as there is a higher tendency for participants to drop out during later rounds (McKenna, 1994)].

Implementation of three Delphi rounds can take anywhere from three to four months (Gordon, 1994). As a result, it seems the best outcome of the Delphi will be achieved with three or four rounds, in order to maximize the accuracy of results and minimize participation drop-outs.

Size of Expert Panel

There is little agreement about the ideal size of the expert panel in a Delphi study (Keeney, 2001). Most studies have used between 15 and 35 panelists (Gordon, 1994). Parente and Anderson-Parente (Parente, 1987) suggested a minimum number of 10 panelists after drop-out. Okoli and Pawlowski (Okoli, 2004) suggested that Delphi group size does not depend on statistical power, but rather on group dynamics for arriving at consensus among experts.

Rowe et al. (Rowe G. W., 1991) proposed that a Delphi can be interpreted as a two-stage process. The focus of the first stage is to limit the bias of individuals through structured interaction, while the second stage is aimed at obtaining a group opinion by using statistical methods. They argue that, as the second stage of a Delphi study is similar to a statistical group, factors that affect the performance of statistical groups (such as the number of the participants) must play an important role within the Delphi process. The impact of the number of panelists has been considered by Brockhoff

(Brockhoff, 1975) (with groups of 5, 7, 9, and 11) and Boje and Murnighan (Boje, 1982) (with groups of 3, 7, and 11). None of these studies found a consistent relationship between panel size and effectiveness criteria.

Hogarth (Hogarth, 1978) proposed an analytical model which yields group validity as a function of the number of experts, their mean individual validity, and the mean correlation among their judgments. Based on this model, he explains that the validity of the group is an increasing function of the number of experts and their mean validity, and a decreasing function of the average inter-correlation among the experts' opinion. Based on this, he concludes that, in the case of expert groups (such as Delphi) where there is some correlation between panelists' judgments, the maximum validity of the group is reached with 8-12 panelists under a wide range of circumstances (in certain conditions the maximum is reached with only 6 panelists). This further reinforces the findings of the Brockhoff and Boje and Murnighan studies. In addition, Ashton (Ashton, 1986) performed an empirical study to evaluate Hogarth's model and his findings, which further confirmed the results of Hogarth's model.

Expert Selection

Unlike statistical group techniques, a Delphi study is not based on a random sample which is a statistical representative of the target population (Keeney, 2001). In contrast, Delphi is aimed at obtaining a judgment/forecast from a panel of experts. Studies have shown expertise of members does have an impact on performance within interacting groups (Bonner, 2002). Therefore, the selection of panel experts is central to the success of the Delphi method (Robinson, 1991). However, this topic has been one of the most neglected aspects in Delphi studies (Okoli, 2004).

An expert panel has been defined as: a group of “informed individuals” (McKenna, 1994) who can be “specialists” in their field (Goodman, 1987), have knowledge about a specific subject (Davidson, 1997); (Green, 1999); (Lemmer, 1998) or are recognized by others in the field (Harman, 1975). At the same time, literature has warned about the drawbacks of illusory expertise (Goodman, 1987), and it has been stated that simply having knowledge of a particular topic does not necessarily mean that someone is an expert (Keeney, 2001). Based on this, one of the main problems of Delphi studies has been the issue of lack of criteria for distinguishing experts from laymen (Gupta, 1996).

Dalkey (Dalkey N. C., 1969) showed that self-rated experts provide more-accurate estimates than self-rated non-experts. Based on this a number of studies used self-rating as a basis for the pert identification. At the same time, the result of a study performed by Larreche and Moinpur (Larreche, 1983) showed that, although self-rated confidence does appear to discriminate between experts and non-experts, experts identified in this fashion are not likely to provide significantly better estimates than the average of the group’s initial judgments, or the judgments of non-experts. Rowe et al. (Rowe G. W., 2004) support this view by showing that confidence is not a good predictor of expertise.

Another technique suggested for identifying experts is the use of external measures (Rowe G. W., 1991). A study by Larreche and Moinpur (Larreche, 1983) showed that use of a simple external measure of expertise appeared to provide significantly better estimates than non-experts identified by the same measure. Based on this, and based on Guidelines provided by Delbecq et al. (Delbecq, 1975), Okoli and

Pawlowski (Okoli, 2004) suggested a five-step procedure for selecting the experts. This process is shown in Figure A.3.

Finally, the issue of expert backgrounds will be discussed. According to Rowe et al. (Rowe G. W., 1991), a key aspect of the selection process is choosing "*experts from varied backgrounds to guarantee a wise base of knowledge.*" Selection of a heterogeneous sample for the Delphi has been mentioned in many studies (Keeney, 2001). This view is also supported by Hogarth's Model (described in the previous section), which shows that group validity has a negative relation with the mean inter-correlation of expert judgments (Hogarth, 1978).

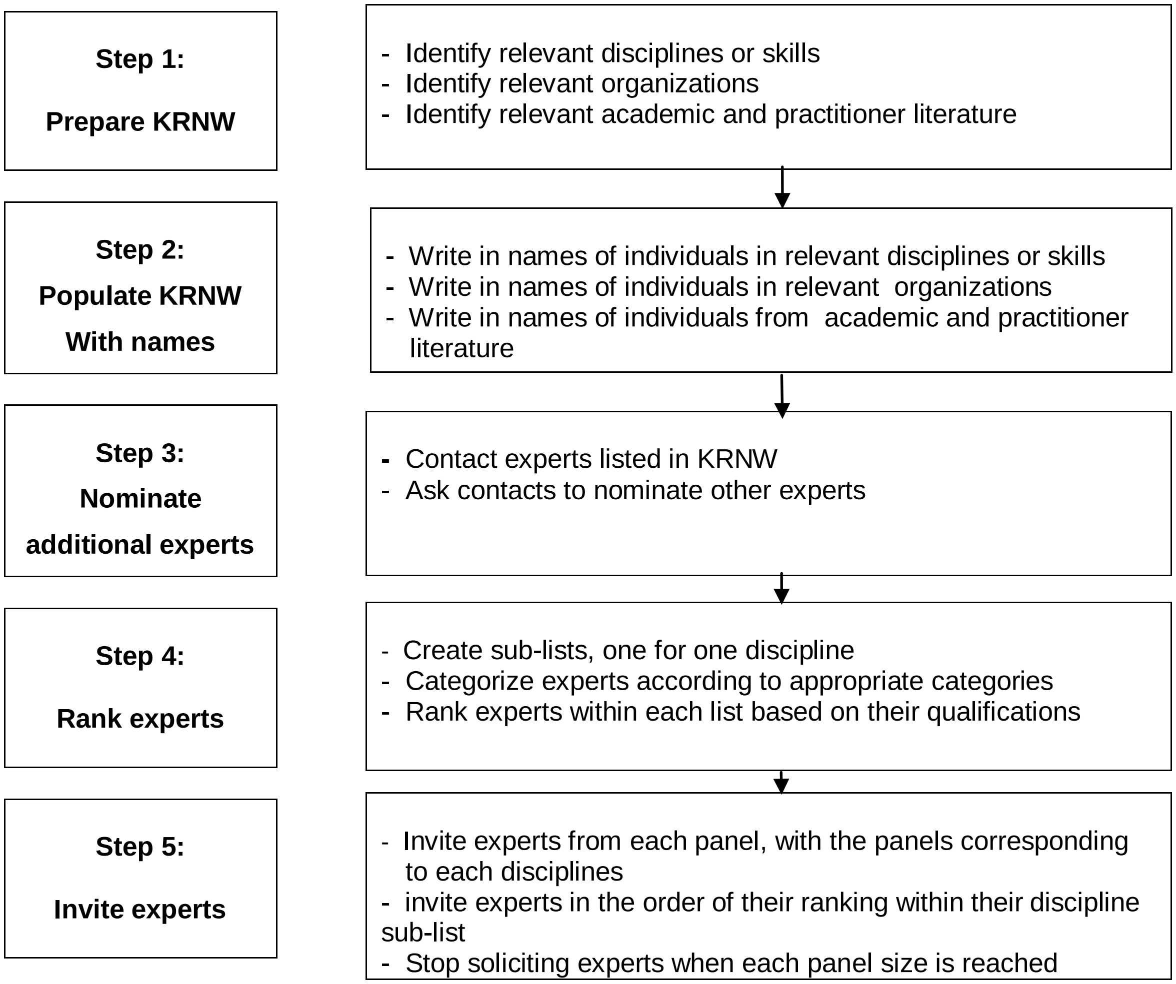


Figure A.3 Five-Step Procedure for Selection of Experts (Okoli and Pawlowski 2004)

APPENDIX B

DEFINITIONS

Basis of Design:

A document that records the concepts, calculations, decisions, and product selections used to meet the Owner's Project Requirements and to satisfy applicable regulatory requirements, standards, and Guidelines. The document includes both narrative descriptions and lists of individual items that support the design process (BCA – Commissioning requirement section 01810).

Building commissioning:

Defined as the process of ensuring, in new construction, that all the subsystems for HVAC, Plumbing, Electrical, Fire/Life safety, and Building Security are operating as intended by the building Owner and as designed by the building architects and engineers. Building commissioning is a quality assurance process for the complexity of modern construction projects. Normally, the commissioning firm is involved from project initiation to project completion. While the service methodology can vary from firm-to-firm and project-to-project, the basic formula for successful building commissioning involves a synergy of pre-construction review of design documents for compliance with the Owner's Project Requirements (OPR), periodic site observations during the construction phase, and systems performance testing as the project nears completion. While the practice of building commissioning is still fairly new in the construction industry, it has quickly become common practice as savvy building Owners and developers have seen substantial returns on their investment. The ultimate goal of the commissioning provider is to deliver to the Owner a project that is on schedule, under budget and with fully operational and optimized systems on day one.

Commissioning Authority:

Commissioning Authority (aka Provider, Entity, and Agent) is the commissioning team leader who is in charge of the commissioning process of projects.

Commissioning Plan:

The commissioning plan is the most important communication document in the commissioning process. The plan should clearly communicate who the commissioning team members are, their responsibilities and their contact information. The plan should also include sample copies of all commissioning check sheets and forms to be used on the project. The plan also defines who has witness authority for which tests. Normally, the commissioning plan is issued in draft form at the beginning of the commissioning project and finalized later in the project when all contractors are identified and all systems are clearly defined (Bochat, 2005).

Commissioning issue:

Violated Owner's Project requirement.

Construction Documents*:*

These include a wide range of documents that will vary from project to project and with the Owner's needs and with regulations, laws, and countries. Construction documents usually include the project manual (specifications), plans (drawings), and general terms and conditions of the contract.

Construction/design Issues:

Any violated Owner’s Project requirement, unidentified tasks of professionals and problems created in the construction process of any project that delayed, added cost, and created ambiguity.

Contract Documents:

These include a wide range of documents that will vary from project to project and with the Owner’s needs and with regulations, laws, and countries. Contract Documents frequently include price agreements, construction management process, subcontractor agreements or requirements, requirements and procedures for submittals, changes, and other construction requirements, timeline for completion, and the Construction Documents.

Nominal Group Technique:

A formal, structured brainstorming process used to obtain the maximum possible ranked input from a variety of viewpoints in a short period of time. The typical approach is a workshop session where a question is presented, the attendees record their responses individually on a piece of paper, the individual responses are recorded on a flip chart without discussion in a round robin fashion, all of the responses are discussed, and then the participants rank their top five responses.

Owner's Project Requirements:

A written document details the functional requirements of a project and the expectations of how it will be used and operated. This document includes project goals, measurable performance criteria, cost considerations, benchmarks, success criteria, and supporting information. (The term *Project Intent* is used by some Owners for their Commissioning Process Owner's Project Requirements.)

Quality Based Sampling:

A process for evaluating a sub-set (sample) of the total population. The sample is based upon a known or estimated probability distribution of expected values; an assumed statistical distribution based upon data from a similar product, assembly, or system; or a random sampling that has scientific statistical basis (BCA – Commissioning requirement section 01810).

Re-Commissioning:

An application of the commissioning process requirements to a project that has been delivered using the commissioning process. This may be a scheduled re-commissioning developed as part of an ongoing commissioning process, or it may be triggered by use change, operations problems, or other needs (BCA – Commissioning requirement; section 01810).

Retro-Commissioning:

The commissioning process applied to an existing facility that was not previously commissioned. This Guideline does not specifically address retro-commissioning.

However, the same basic process needs to be followed from pre-design through occupancy and operations to optimize the benefits of implementing the commissioning process philosophy and practice (BCA – Commissioning requirement section 01810).

Systems Manual:

A system-focused composite document that includes the operation manual, maintenance manual, and additional information of use to the Owner during the occupancy and operations phase (BCA – Commissioning requirement section 01810).

Test Procedure:

A written protocol that defines methods, personnel, and expectations for tests conducted on components, equipment, assemblies, systems, and interfaces among systems. The test procedures are specified in the Technical Specifications sections of the contract documents. Performance testing covers the dynamic functions and operations of equipment and systems using manual or monitoring methods. Performance testing is the dynamic testing of systems under full operation. Systems are tested under various modes, such as during low cooling loads, high loads, component failures, unoccupied, varying outside air temperatures, fire alarm, power failure, etc. The systems are run through all the control system's sequences of operation and components are verified to respond as the sequences state (BCA – Commissioning requirement section 01810).

Total Building Commissioning:

Is quality process for achieving, validating and documenting that the facility and its systems and assemblies are planned, designed, installed, tested and capable of being operated and maintained to perform in conformity with the needs of the client and the design intent. The building commissioning is not a layer, but a catalyst for communication that makes quality solutions possible.

Training Plan:

A written document that details the expectations, schedule, budget, and deliverables of commissioning process activities related to training of project operating and maintenance personnel, users, and occupants (BCA – Commissioning requirement section 01810).

Validation:

The establishment of documented evidence which provides a high degree of assurance that a system will consistently perform in accordance with the design intent.

Verification:

The process by which specific documents, components, equipment, assemblies, systems, and interfaces among systems are confirmed to comply with the criteria described in the Owner's Project Requirements.

APPENDIX C
BUILDING COMMISSIONING GUIDELINES

Guideline 0-2005: General Principles & Procedures developed by National Institute of Building Sciences and ASHRAE. Guideline 0-2005 was published to address underlying quality based commissioning processes without reference to a specific area, and is updated every five years. This Guideline has been developed as a joint program between ASHRAE and NIBS.

Guideline 1-2007: Mechanical and Energy Systems. Guideline 1-1996 HVAC&R Technical Requirements for the Commissioning Process is now **Guideline 1-200X or 1.1-2007**

Guideline 2: Structural Systems - ASCE, Structural Systems TBD later. No report or publication is available.

Guideline 3-2006: Exterior Envelope Systems. Development of NIBS Guideline 3-2006, which provides specific guidance on technical requirements for commissioning of the building exterior enclosure, began formally in early 2004. At that time, NIBS formed a committee to document the best practices to achieve exterior enclosure systems that performed according to and meet the Owner's Project Requirements. NIBS Guideline 3-2006 is process-oriented to address any performance objectives required by an Owner for the exterior enclosure including the control of heat flow, air flow, noise, fire, light, infrared, ultraviolet, rain penetration, moisture, structural performance, durability, security, reliability, aesthetics, value, constructability, maintainability, and sustainability. This Guideline has been developed as a joint program between ASHRAE and NIBS.

Guideline 4: Roofing Systems. Guidelines for the Design of Energy-Efficient Roof Systems was updated in 2009; this manual is intended for design professionals who want to specify energy-efficient roof systems, as well as those who need to meet the requirements of the recently updated ASHRAE-Standard 90.1-2007, "Energy Efficient Design of New Buildings Except for Low-Rise Residential." This manual is best used with The NRCA Roofing Manual: Membrane Roof-Systems—2007 and the Moisture Control section of The NRCA Roofing and Waterproofing Manual, Fifth Edition.

Guideline 5: Interior Systems - TBD later. No report or publication is available.

Guideline 6: Elevator Systems. - TBD later. No report or publication is available.

Guideline 7: Plumbing Systems. - TBD later. No report or publication is available.

Guideline 8: Lighting Systems. The Guidelines for Specification Integrity-2009 Edition the International Association of Lighting Designers (IALD), in conjunction with the Lighting Industry Resource Council, has created the following Guidelines for Specification Integrity, which suggests specific actions for building and maintaining a specification of high integrity.

Guideline 9: Electrical Systems. - TBD later. The NECA 90-2004 Guideline was published in 2004 and is approved as an American National Standard (ANS). This Guideline describes procedures for commissioning newly installed or retrofitted building electrical systems. It defines the process of commissioning building electrical systems and gives sample Guidelines for gaining optimum system performance that comply with design, specifications, and industry-accepted codes and standards. All the information in this publication is intended to conform to the National Electrical Code (ANSI/NFPA 70).

Guideline 10: Fire Protection Systems. – TBD later. The NFPA provides Guideline NFPA3: Standard for the Commissioning and Integrated Testing of Fire Protection and Life Safety Systems. This Guideline outlines the procedures, methods, and documentation for each phase of the commissioning process for all types of active fire protection systems from planning to occupancy and throughout the life cycle of the building.

Guideline 11: Telecommunication Systems. - TBD later. All types of telecommunications cabling systems intended to support voice, data, video, and other low voltage, power limited applications.

Guideline 12: Seismic Protection. – TBD later. No report or publication is available.

ADDITIONAL GUIDELINES

There are also Guidelines for interior indoor quality developed by:

American Society of Heating, Refrigerating and Air-Conditioning Engineers, The American Institute of Architects, Building Owners and Managers Association International, Sheet Metal and Air Conditioning Contractor's National Association, U.S. Environmental Protection Agency, U.S. Green, Building Council, This publication was developed under the auspices of ASHRAE Special Project 200, in October 2009.

APPENDIX D
QUALIFICATION OF EXPERTS MATRIX
AND
REVIEWED PROJECTS

Qualification of Experts*:*

Experts selected for reviewing the OPRTSS were required to have professional registration with a minimum 10 years of experience in design and construction of multi story concrete or steel framed structures. The Matrix below shows the information for each of the expert selected:

Table D.1 Expert panel qualifications and information

Expert	Location	Job title	Years of experience	Professional license	Concrete structures	Steel structures
1	Atlanta	Partner	28	Yes	Yes	Yes
2	Atlanta	Partner	38	Yes	Yes	Yes
3	Atlanta	Partner	22	Yes	Yes	Yes
4	Atlanta	Project Engineer	11	Yes	Yes	No
5	Atlanta	Partner	28	Yes	Yes	Yes
4	Atlanta	Project Engineer	32	Yes	Yes	Yes
5	Atlanta	Partner	40	Yes	Yes	Yes
6	Santa Clara	CEO	36	Yes	Yes	Yes

Table D.1 Continued

Expert	Location	Job title	Years of experience	Professional license	Concrete structures	Steel structures
8	Los Angeles	Project Engineer	26	Yes	Yes	Yes
9	Canton	CEO	33	Yes	Yes	Yes
10	Cummings	Partner	32	Yes	Yes	Yes
12	Stone Mountain	Project Engineer	24	Yes	Yes	Yes
13	Riverdale	CEO	38	Yes	Yes	Yes
14	Alpharetta	CEO	28	Yes	Yes	Yes
15	Alpharetta	Project Engineer	12	Yes	No	Yes
16	Alpharetta	Partner	32	Yes	Yes	Yes
17	Roswell	CEO	28	Yes	No	Yes
18	Roswell	Project Engineer	12	Yes	No	Yes

REVIEWED PROJECTS (CONTRACT ADMINISTRATION)

Projects reviewed were located in east and southeast of United States.

1) 1,000,000 square feet/35 Story residential concrete structure.
2) 750,000 square feet/45 story condominium project of concrete frame.
3) 420,000 square feet/18 story hotel project with steel frame.
4) 162000 square feet/8 story office building with structural steel frame.
5) 650,000 square feet/25 story office tower with concrete frame.
6) 610,000 square feet/27 story condominium of concrete frame.
7) 620,000 square feet/25 UPS corporate office of concrete frame.

8) 615,000 square feet/19 story bank with structural steel frame.

9) 220,000 square feet/21 story hotel project with concrete frame.

10) 465,000 square feet/20 story office tower with steel frame.

11) 340,000 square feet/6 story mix use building.

12) 380,000 square feet/6 story mix use building.

13) 500,000 square feet/20 story office tower with concrete frame.

14) 420,000 square feet/6 story mix use building.

15) 140,000 square feet/7 story hotel project with steel frame.

16) 160,000 square feet/6 story bank with structural steel frame.

17) 350,000 square feet/6 story mix use building.

18) 550,000 square feet/8 story mix use building.

19) 520,000 square feet/28 story office project with steel frame.

20) 880,000 square feet/23 story condominium of concrete frame.

21) 412,000 square feet/6 story hospitality project with steel frame.

22) 300,000 square feet/16 story hotel project with concrete frame.

23) 200,000 square feet/5 story hospitality project with concrete frame.

24) 680,000 square feet/24 story office tower with concrete frame.

25) 192,000 square feet/23 story condominium project of concrete frame.

26) 625,000 square feet/20 story bank with structural concrete frame.

27) 340,000 square feet/18 story hotel project with concrete frame.

28) 390,000 square feet/6 story mix use building.

29) 650,000 square feet/18 story bank with structural concrete frame.

30) 320,000 square feet/6 story mix use building.

REVIEWED COMMISSIONED PROJECTS

Helen Diller Cancer Research Building 17C, University of California,
San Francisco, California
Services: commissioning
Industry: Healthcare
Size: 163,000 SF
Construction Cost: $108 million
Architect: Rafael Viñoly
Contractor: Hunt Construction Group

Justice Center, Thornton, Colorado
Services: commissioning
Industry: Municipal / Judicial
Construction Cost: $19.8 million

Federal Courthouse, General Services Administration,
Newport News, Virginia
Services: commissioning
Industry: Federal / Judicial
Size: 38,000 GSF
Architect: Construction Engineering Consultants

San Joaquin Administration Building, Stockton, California
Services: LEED commissioning
Industry: Office and Administration
Size: 250,000 SF
Construction Cost: $95 million
Architect: Fentress Architects
Contractor: Hensel-Phelps Construction
Isaac Municipal Court House, Colorado Springs Utilities, Colorado Springs, Colorado (2003)

Services: Retro-Commissioning and energy services

Industry: Municipal

Size: 105,000 SF Built in 1997

Annual Energy Cost Savings: $58,621

Payback Period: 2.3 years

Covenant Healthcare Buildings, the Trane Company, Saginaw, Michigan

Services: Retro-commissioning and energy services

Industry: Health Care

Size: 1.5 million SF

Annual Energy Cost Savings: $861,000

Architect: TSSF Architects

Starz Entertainment Corporate Headquarters, Englewood, Colorado

Services: Re-Commissioning and energy services

Industry: Retail/Commercial

Size: 308,000 SF with 245,000 SF listed as conditioned

Annual Energy Cost Savings: $52,525

Payback Period: 0.33 years

Pepsi Center, Denver, Colorado

Services: Re-commissioning

Industry: Events Center

Size: 675,000 SF

Annual Energy Cost Savings: $48,980

Payback Period: 4.87 years

APPENDIX E
SURVEY AND QUESTIONNAIRES

Survey

Cover sheet

Date:

Dear ________

As you may know, I am working toward establishing a framework for commissioning of the structural system with the help of published Guidelines from ASHRAEs' Guideline 0-2005. In order to finish this task, I need your expertise and input. I have attached a questionnaire that I prepared for your input. Please feel free to add any additional notes and comments where you feel necessary to help me complete this framework. Please distribute this questionnaire to your Colleagues in your organization, and have them e-mail me their answers. I appreciate your help in advance.

Sincerely,

Soheil Rouhi

On the list provided, please cross out the items that have no impact on the structural performance of the project. If you need to add any other item, fell free to add them in the end of the list. Also please highlight the sections that have the most impact on the structural performance of a project.

Please pick the five most important structural issues you faced in your past experience in the following list. If you need to add to the list, please do so.

1) Deflection
2) Flatness
3) Levelness
4) Vibration
5) Noise transmission
6) Floor/Roof penetration/openings
7) Column alignment
8) Window washing
9) Area used for storage
10) Access to loading docks
11) Elevator supports and delivery
12) Missing structural support embeds
13) Brick supports
14) Issues due to grading
15) Site walls
16) Underground utility structure issues

17) Dimensional conflicts

18) Miss aligned dowels

19) Future expansions

20) Issues with design of curtain walls

21) Parapet copings

22) Vertical expansion joints

23) Horizontal expansion joints

24) Special loadings

25) Underground pipes to building penetrations

26) Control joints in slab on grade

27) Utility lines conflict with structure

28) Structural fire protections

29) Frost penetrations

30) Loading for special areas.

31) Design of curtain walls

32)

Questionnaire

Cover sheet

Date

Dear Mr.:

I want to thank you in advance for taking the time out of your busy schedule and giving your valuable input regarding my Ph.D. dissertation: Owner's Project Requirements for Total Structural Systems (OPRTSS) of the Total Building Commissioning.

As a recognized expert in the field of Structural Engineering, I believe that your knowledge and experience will provide invaluable information for a critical phase of my doctoral research. During this phase of my work, a group of experts and experienced professionals will participate in two surveys to identify the most critical element in construction effected by structural performance as it is recommended by the Delphi method. The surveys are scribed below:

Survey 1: Evaluate the performance of those variables which most affect the construction process.

Survey 2: Participate in the second round of survey 1 to gain some level of consensus.

I have attached a detailed description of the research and its criteria for your reference.

Thank you in advance for assisting in my research. I appreciate your participation in this survey and your expertise and experience in this field. If you need any additional information about this research, please do not hesitate to ask. I will provide you with the result of my dissertation when completed, if you so desire.

Sincerely

Soheil Rouhi

Consent form

Georgia Institute of Technology

Project title: Framework for Owner's Project Requirements for the Total Structural Systems (OPRTSS) of the Total Building Commissioning.

Investigator: Soheil Rouhi

You are being asked to be a volunteer in a research study. You are encouraged to take your time in making your decision.

Purpose:

The purpose of this study is to establish a framework for the Owner's Project Requirements for the Total Structural Systems (OPRTSS) of the Total Building Commissioning, based on a set of developed performance aspect of this process. This framework will be based on an expert judgment study. The expert judgment will be acquired through two anonymous surveys. A total of twenty five experts have been identified to participate in these surveys.

Procedures:

If you decide to be in this study, your part will involve participating in two surveys over the course of a month. Each survey will require 30 minutes, and you will have 7 days to respond to each survey.

Risks/Discomforts:

The following risks/discomfort may occur as a result of your participation in the study:

You may face some risks or discomforts due to being part of this study. The risks involved are no greater than those involved in daily activities such as filling out an online survey.

Benefits:

The following benefits to you are possible as a result of being in this study:

You will be provided with the results of the study, and at your request a copy of the dissertation will be sent to you in PDF format.

Compensation to you:

There won't be any monetary compensation for participants in this study. However, findings of this study will be shared with participants.

Confidentiality:

The following procedures will be followed to keep your personal information confidential in this study. The data that is collected about you will be kept private to the extent allowed by law. To protect your privacy, your records will be kept under a code number rather than by name. Your records will be kept in locked files and only study staff will be allowed to look at them. Your name and any other fact that might point to you will not appear when results of this study are presented or published.

To make sure that this research is being carried out in the proper way, the Georgia Institute of Technology IRB may review study records. The office of Human Research Protections may also look at the study records.

Costs to you:

There are no costs to you for participating in this study, other than the time requirements for filling out the surveys.

In case of injury/Harm:

If you are injured as a result of being in this study, please contact Dr. Saeid Sadri at sadri@gatech.edu.

Neither the principal Investigator nor the Georgia Institute of Technology has made provision for payment of costs associated with any injury resulting from participation in this study.

Subject Rights:

1) Your participation in this study is voluntary. You do not have to be in this study if you don't want to participate.
2) You have the right to change your mind and leave the study at any time without giving any reason, and without penalty.
3) You will be given a copy of this consent form to keep.
4) You do not waive any of your legal rights by signing this consent form.

Questions about the study or your Rights as a Research Subject:

1) If you have any questions about the study, you may contact Dr. Saeid Sadri at sadri@gatech.edu.
2) If you have any questions about your rights as a research subject, you may contact Ms. Melanie Clark at Georgia Institute of Technology (404) 894-6942.

____

Participant Name and signature.

Questionnaire

Today more than ever litigation and construction problems are rising due to the complexity of the projects and the demand for optimum project performance. Owners must compete to meet demanding clients, working environments, new technology, government regulations and requirements for sustainability. As the Total Building Commissioning progresses one essential part of any project is the structural system. The purpose of this investigation is to analyze and evaluate some of the structural issues that arise in the construction process due to the Owner's specific requirement and demand to develop a Framework for the Owner's Project Requirements for the Total Structural Systems (OPRTSS). Please carefully review the following document which is the proposed Owner's Project Requirements for Total Structural Systems (OPRTSS) of a multi story concrete, steel or mixed use type projects, and answer questions provided for each item.

Question and information:

Some of the information you read in the following questions may seem to be beyond the capacity of an average owner representative to understand. With building commissioning the owner, with help from Commissioning consultants will provide the information needed for this OPRTSS. Please express your answers using a scale of 1 to 5 (1 having no impact, 2 having low impact, 3 having moderate impact, 4 having high and 5 having extreme impact) as the section's impact on structural performance during project delivery of a concrete or steel framed project.

Owner's Project Requirements for Total Structural Systems (OPRTSS)

1. Building Objectives: List the objectives that are unique to the structural system and that expand upon the objectives and goals described in Whole Building Commissioning.

Please mark your answer.				
1	2	3	4	5

2. Project Documentation requirements: including format for submittals, training, materials, reports, and the System Manual. Consideration should be given to use of electronic format documents and records where appropriate.

Please mark your answer.				
1	2	3	4	5

Site Description and Requirements

3. List criteria that have major influence on the Structural development of the building design. Coordinate with Site and Civil Engineering plans.

Please mark your answer.				
1	2	3	4	5

4. Neighborhood / Context

Describe the influence of the project site, neighborhood and context.

Please mark your answer.
1 2 3 4 5

5. Existing Buildings

Describe existing buildings and their influence on the design.

Please mark your answer.
1 2 3 4 5

Master Plan

6. Describe existing or in progress master planning issues which affect the design.

Please mark your answer.
1 2 3 4 5

Circulation / Access

7. Describe the opportunities and constraints imposed by circulation issues and required access.

Please mark your answer.
1 2 3 4 5

8. Major Building Access:

Please mark your answer.				
1	**2**	**3**	**4**	**5**

Secondary Building Access:

Deliveries and Services:

- 9. Trash Docks and Compactors.

Please mark your answer.				
1	**2**	**3**	**4**	**5**

- 10. Kitchen, Cafeteria or other food service Deliveries and Services.

Please mark your answer.				
1	**2**	**3**	**4**	**5**

- 11. Lab, Animal, GMP or other special Deliveries and Services.

Please mark your answer.				
1	**2**	**3**	**4**	**5**

- 12. Ambulance or Emergency Service.

Please mark your answer.				
1	**2**	**3**	**4**	**5**

• 13. Fire truck path on elevated structures.

Please mark your answer.				
1	**2**	**3**	**4**	**5**

Zoning

14. Describe the allowable building footprint, maximum height, FAR, and other zoning issues that affect the design. Coordinate with the Site/Civil section.

Buildable Dimensions and Area:

Please mark your answer.				
1	**2**	**3**	**4**	**5**

15. Maximum Height:

Please mark your answer.				
1	**2**	**3**	**4**	**5**

16. Upper Level Setbacks:

Please mark your answer.				
1	**2**	**3**	**4**	**5**

17. User Requirements: Insert additional user requirements.

Not applicable.

Zoning or Planned Unit Development Restrictions on Materials or design

18. Describe any special restrictions on the design of the building such as exterior materials, roof shapes, percent glazed area, etc.

Please mark your answer.				
1	**2**	**3**	**4**	**5**

Local, Neighborhood or Community Review Boards or Approvals

19. Describe any special approvals of the building design that may be required.

Please mark your answer.				
1	**2**	**3**	**4**	**5**

Building Code

20. Insert Authority Having Jurisdiction and Codes in Affect

City of (insert city name)

Please mark your answer.				
1	**2**	**3**	**4**	**5**

21. International Building Code with Amendments (insert year and amendments)

Please mark your answer.				
1	**2**	**3**	**4**	**5**

22. Construction Types

Describe building type (insert building type) and if fully sprinkled

Please mark your answer.
1 2 3 4 5

23. Structural fire rating and protection

Please mark your answer.
1 2 3 4 5

24. Allowable Area and Height

Please mark your answer.
1 2 3 4 5

Sustainability

25. Describe the Owner's and Design Professional's criteria for sustainability for the project. Describe any specific programs or measuring tools that may be required to measure energy conservation issues such as LEED ratings.

Please mark your answer.
1 2 3 4 5

26. Energy Conservation

Please mark your answer.
1 2 3 4 5

27. Life Cycle Costing

Please mark your answer.
1 2 3 4 5

28. Recycled Materials

Please mark your answer.
1 2 3 4 5

Existing Facilities

29. Identify special criteria for renovations, restorations, additions, alterations or any other work on an existing facility. Coordinate this overall section with the "Existing" paragraphs in the remainder of the OPR. Coordinate with the code analysis and life safety section.

Please mark your answer.
1 2 3 4 5

30. Note that building code, energy conservation and accessibility requirements may affect areas of the building beyond the owners identified scope.

Note that any change of use or occupancy frequently triggers additional code requirements. Adding conference rooms or cafeterias to existing office buildings is a commonly missed change of use.

Please mark your answer.
1 2 3 4 5

Program

Functional Criteria

Describe needs for building functions and arrangements of major areas and use such as storage, lobby, corridor, assembly room, special function, etc. If separate Criteria or Program Report is included, give a basic list of program requirements here.

31. Primary Functions

Please mark your answer.
1 2 3 4 5

32. Support Functions

Please mark your answer.
1 2 3 4 5

Structural Criteria

33. ***Loads and Serviceability Criteria Standards***

American Society of Civil Engineers, "Minimum Design Loads for Buildings and Other Structures" (ASCE 7). General Services Administration (GSA) "Facilities Standards for the Public Buildings Service - Metric Version" PBS-PQ100.1.

Please mark your answer.
1 2 3 4 5

Progressive Collapse

34. Identify need for progressive collapse analysis. Progressive collapse will be analyzed in accordance with Progressive Collapse Analysis and Design Guidelines for New Federal Office Buildings and Major Modernization Projects.

Please mark your answer.
1 2 3 4 5

Enclosure Loads

Soil capacities and Foundation

Identify the followings:

e) 35. Applicable bearing loads capacity of soils and rock from geotechnical report.

Please mark your answer.
1 2 3 4 5

f) 36. Loads applied to enclosure from soil and ground water.

Please mark your answer.
1 2 3 4 5

g) 37. Specify Type of foundation for the structures.

Please mark your answer.
1 2 3 4 5

h) 38. Specify frost penetration.

Please mark your answer.
1 2 3 4 5

Roof Live Loads

39. Minimum live load shall be XXXXXX. Roof live loads [will] [will not] be reduced per code.

Please mark your answer.
1 2 3 4 5

40. Service Load Paths - Specific areas will be identified and designed for appropriate loadings to allow for movement of mechanical equipment components across the roof if required. The values of the loads will be based upon the type of equipment to be moved as identified when the building program is detailed.

Please mark your answer.
1 2 3 4 5

Roof Ponding Loads

41. Roofs will be designed for the weight of ponded water considering all primary drainage is blocked. The depth of ponded water shall include the deflection of the roof structure and the distance above the scupper base as required to account for flow. The height of flow will be based on the serviced area of roof, the appropriate volume of rainwater and the size of the scupper.

Please mark your answer.				
1	2	3	4	5

Snow Loads

42. The ground snow load (pg) established by Code for the Project site is XXXXXXX.

Please mark your answer.				
1	2	3	4	5

43. Importance factor (Is) of XXXXXXXX in calculating the snow loads.

Please mark your answer.				
1	2	3	4	5

44. Exposure factor (Ce): XXXX in calculating the snow loads based on a XXXXX exposure category X.

Please mark your answer.				
1	2	3	4	5

45. Thermal factor (Ct): XXXXX in calculating the snow loads based on XXXXXXXXXXXX.

Please mark your answer.				
1	**2**	**3**	**4**	**5**

46. Calculated “flat roof” snow load (psf): XXXXXX.

Please mark your answer.				
1	**2**	**3**	**4**	**5**

47. Snow Drifting – Adjacent to vertical projections, such as parapets, changes in roof elevation, etc., the snow load will be increased above the “flat roof” value in conformance with Code established parameters. Specific snowdrift values will be determined after development of the final roof configuration.

Please mark your answer.				
1	**2**	**3**	**4**	**5**

Wind Loads

48. The Basic Wind Speed established by Code for the project site is XXXXX.

Please mark your answer.				
1	**2**	**3**	**4**	**5**

49. Importance factor: [Increase] [decrease] the wind load based on an importance factor of XXXX.

Please mark your answer.				
1	**2**	**3**	**4**	**5**

50. Exposure category: Exposure X.

Please mark your answer.				
1	**2**	**3**	**4**	**5**

Specify the following:

d) 51. Design structure as an enclosed or open structure

Please mark your answer.				
1	**2**	**3**	**4**	**5**

e) 52. Window requirement for wind prone area

Please mark your answer.				
1	**2**	**3**	**4**	**5**

Seismic Loads

53. Identify Seismic Performance Category and the Components Performance Criteria factor.

Please mark your answer.				
1	**2**	**3**	**4**	**5**

54. Identify site classification and soil type.

Please mark your answer.
1 2 3 4 5

Flood loads

55. Specify flood requirement per Section 1612 of IBC.

Please mark your answer.
1 2 3 4 5

Other special Loads

56. Specify any other special loading required by future tenant use and equipments.

Please mark your answer.
1 2 3 4 5

General requirement with consideration for other common difficulties in the construction process.

Strength

57. Specify all material strengths used in the project.

Please mark your answer.
1 2 3 4 5

Serviceability

Deflection

58. Structural elements will be designed within the deflection control limits below except where the material codes require more restrictive criteria.

Table E.1 – Deflection Criteria

Framing Element	**Loading**	**Control Criteria**	**Owners additional requirement**
Floor Member	Live + Dead Load	Span/240	
Floor Member	Live Load	Span/360	
Floor Member Supporting Glass	Superimposed Load	Span/480	
Floor Member Supporting Masonry	Superimposed Load	Span/600	
Typical Roof Member	Live + Dead Load	Span/180	
Typical Room Member	Live Load	Span/240	
Elevator Supports	Live Load	Span/1666	
Sunscreens & Canopies	Live Load	Span/175	

Please mark your answer.

1 2 3 4 5

Drift

59. Inter-story (between any two floors) and total drift control limits: Height/XXX.

Drift due to seismic loads: XXXXX.

Please mark your answer.
1 2 3 4 5

Analysis:

Overall Structural plans

Specify the following:

60. Specify requirement for the use of Building Information Modeling (BIM)

Please mark your answer.
1 2 3 4 5

61. Coordinate all dimensions with Architectural plans

Please mark your answer.
1 2 3 4 5

62. Provide additional dimensional plans for all vertical supporting systems.

Please mark your answer.
1 2 3 4 5

Grading, excavation and site work.

Specify that a final grading plan must prepared by Civil Engineer of record and the plan must be signed by Architect and Structural Engineer of record to state that they have covered:

63. Location of foundation steps.

Please mark your answer.
1 2 3 4 5

64. Specified top elevation of all foundation elements such as footings, plies, caissons etc.

Please mark your answer.
1 2 3 4 5

65. Location and details for all utility pipes, etc. thru structure

Please mark your answer.
1 2 3 4 5

66. Specify the responsible party for the design and detail of all site walls and site structures, such as retaining walls, detention or retention vaults, underground storage tanks, etc.

Please mark your answer.
1 2 3 4 5

67. Specify LEED requirement for materials used.

Please mark your answer.
1 2 3 4 5

Foundation

Specify the followings:

68. Specify type of foundation used for each part of the project.

Please mark your answer.
1 2 3 4 5

69. Specify LEED requirement for materials used.

Please mark your answer.
1 2 3 4 5

70. Specify requirement for vertical and horizontal expansion joint in foundation walls.

Please mark your answer.
1 2 3 4 5

Slab on grade

Specify the followings:

71. Slab sub-grade requirements.

Please mark your answer.				
1	**2**	**3**	**4**	**5**

72. Specify LEED requirement for materials used.

Please mark your answer.				
1	**2**	**3**	**4**	**5**

73. Waterproof membrane.

Please mark your answer.				
1	**2**	**3**	**4**	**5**

74. Control/Construction joint spacing

Please mark your answer.				
1	**2**	**3**	**4**	**5**

75. Slopes for drainage and other consideration.

Please mark your answer.				
1	**2**	**3**	**4**	**5**

76. Requirement for steps.

Please mark your answer.
1 2 3 4 5

Vertical Load Resisting System

Specify the following:

77. Type of material

Please mark your answer.
1 2 3 4 5

78. Location with proper dimensional information

Please mark your answer.
1 2 3 4 5

79. Fire protection

Please mark your answer.
1 2 3 4 5

80. Desired vibration control

Please mark your answer.
1 2 3 4 5

81. Future use consideration

Please mark your answer.

1 2 3 4 5

82. LEED requirement for materials

Please mark your answer.

1 2 3 4 5

83. Coordination with all utility systems

Please mark your answer.

1 2 3 4 5

84. Consideration for future expansion

Please mark your answer.

1 2 3 4 5

Floor System

Specify the following:

85. Floor type

Please mark your answer.

1 2 3 4 5

86. Floor finishes; slope and steps

Please mark your answer.				
1	**2**	**3**	**4**	**5**

87. Flatness

Please mark your answer.				
1	**2**	**3**	**4**	**5**

88. Levelness

Please mark your answer.				
1	**2**	**3**	**4**	**5**

89. Top of structure elevations

Please mark your answer.				
1	**2**	**3**	**4**	**5**

90. Desired deflection

Please mark your answer.				
1	**2**	**3**	**4**	**5**

91. Desired vibration control

Please mark your answer.
1 2 3 4 5

92. Coordination with utility systems and other consultants for openings in floors.

Please mark your answer.
1 2 3 4 5

93. Consideration for future use

Please mark your answer.
1 2 3 4 5

94. LEED requirement for materials

Please mark your answer.
1 2 3 4 5

95. Consideration for future expansion

Please mark your answer.
1 2 3 4 5

96. Insulation

Please mark your answer.

1 2 3 4 5

Roof System

Specify the following:

97. Roof type and material type

Please mark your answer.

1 2 3 4 5

98. Roof drain and slopes

Please mark your answer.

1 2 3 4 5

99. Top of structure elevations

Please mark your answer.

1 2 3 4 5

100. Utility systems location and specification and supports.

Please mark your answer.

1 2 3 4 5

101. Window washing supports

Please mark your answer.

1 2 3 4 5

102. Coordination with utility systems and other consultants for openings in roof

Please mark your answer.

1 2 3 4 5

103. Consideration for future expansion

Please mark your answer.

1 2 3 4 5

104. LEED requirement for materials

Please mark your answer.

1 2 3 4 5

Exterior curtail walls

Specify the following

105. Wall finishes and requested limit on movement and deflection

Please mark your answer.

1 2 3 4 5

106. Party responsible for design and detailing.

Please mark your answer.
1 2 3 4 5

107. Specify require horizontal and vertical expansion/control joints.

Please mark your answer.
1 2 3 4 5

108. Party in charge of design and detailing of roof screens

Please mark your answer.
1 2 3 4 5

109. Exterior door and window requirements in wind prone area

Please mark your answer.
1 2 3 4 5

110. LEED requirement for materials

Please mark your answer.
1 2 3 4 5

Lateral Load Resisting System

Specify the following

111. Any required special inspection for buildings of over 75 feet in height and buildings located in seismic category ‘E’ and occupancy category of I and II over two story in height (section 1709 of IBC)

Please mark your answer.
1 2 3 4 5

112. Fire protection

Please mark your answer.
1 2 3 4 5

113. Floor diaphragm connections

Please mark your answer.
1 2 3 4 5

114. Consideration for future use

Please mark your answer.
1 2 3 4 5

115. LEED requirement for materials

Please mark your answer.
1 2 3 4 5

Construction variables

Specify the following

116. Party responsible for design of underground utility system structures.

Please mark your answer.
1 2 3 4 5

117. Party responsible for design of site retaining walls

Please mark your answer.
1 2 3 4 5

118. Party in charge of site paving

Please mark your answer.
1 2 3 4 5

119. Party responsible for design of project signs

Please mark your answer.
1 2 3 4 5

120. Party responsible for design of Architectural ornaments and canopies.

Please mark your answer.
1 2 3 4 5

121. Parties responsible for the design of prefabricated items and party

Please mark your answer.				
1	**2**	**3**	**4**	**5**

122. responsible for their connections to main structure

Please mark your answer.				
1	**2**	**3**	**4**	**5**

123. Party responsible for embedded plate coordination

Please mark your answer.				
1	**2**	**3**	**4**	**5**

124. Party responsible for the design of stairs, handrails guardrails, elevator

Please mark your answer.				
1	**2**	**3**	**4**	**5**

125. Machine rooms, elevator guide rails, elevators lateral support system.

Please mark your answer.				
1	**2**	**3**	**4**	**5**

126. Party responsible for design and detailing of barrier cable system and their connections.

Please mark your answer.
1 2 3 4 5

127. LEED requirement for materials.

Please mark your answer.
1 2 3 4 5

Owner's Additional Requirements

128. Deflection: Specify any additional requirement for limit on deflection.

Please mark your answer.
1 2 3 4 5

129. Future expansion: Specify any future expansion that needs to be considered at design of the structure.

Please mark your answer.
1 2 3 4 5

130. Vibration: Specify any additional requirement for limit on vibration of the structure.

Please mark your answer.
1 2 3 4 5

131. Noise Transmission: Specify any additional requirement for limit on noise transmission due to structural behavior.

Please mark your answer.				
1	**2**	**3**	**4**	**5**

132. Progressive collapse: Specify if your project needs to be considered for prevention of progressive collapse.

Please mark your answer.				
1	**2**	**3**	**4**	**5**

133. Flatness/Levelness: Specify any additional requirement for structural finishes.

Please mark your answer.				
1	**2**	**3**	**4**	**5**

134. Maintenance: Specify any additional requirement for structural maintenance.

Please mark your answer.				
1	**2**	**3**	**4**	**5**

Questionnaire

Cover sheet

Date

Dear Mr.:

I want to thank you in advance for taking the time out of your busy schedule and giving your valuable input regarding my Ph.D. dissertation: Owner's Project Requirements for Total Structural Systems (OPRTSS) of the Total Building Commissioning.

As a recognized expert in the field of Structural Engineering, I believe that your knowledge and experience will provide invaluable information for critical phase of my doctoral research. During this phase of my work, a group of experts and experienced professionals will participate in a series of two surveys to identify the most critical element in construction effected by structural performance as it is recommended by Delphi method. The surveys are scribed below:

Survey 2: Evaluate the performance of those variables which most affect the construction process.

Survey 3: Participate in second round of survey 2 for the final verification and validation of Framework for Owner's Project Requirements for Total Structural Systems (OPRTSS) of the Total Building Commissioning (Guideline 2) to certify that the final OPRTSS is inclusive.

Thank you in advance for assisting in my research. I appreciate your participation in this survey and your expertise and experience in this field. If you need any additional information about this research, please do not hesitate to ask. I will provide you with the result of my dissertation when completed, if you so desire.

Sincerely

Soheil Rouhi

Question:

Please respond to the following question:

Is the attached Framework for Owner's Project Requirements for Total Structural Systems (OPRTSS) inclusive?

___ Yes

___ No

____

Participant Name and signature.

APPENDIX F

INFORMATIVE ANNEX J

OWNER'S PROJECT REQUIREMENTS

(ASHRAE, Guideline 0-2005)

A general format for an Owner's Project Requirements document is presented in this appendix. The structure provided is intended to encompass the facility requirements and enable the addition of sections depending upon the systems and assemblies to be constructed.

Introduction

Includes an overview of the project and the general reasons why the project is being undertaken. A description of the Owner's processes (Commissioning Process) is typically contained in this section.

Key Owner's Project Requirements:

Includes a listing of the key Owner's Project Requirements that the Commissioning Process will focus upon and that the Owner (Commissioning Team) has determined are critical to the success of the project.

General Project Description:

The size and scope of the project are included in this section.

Objectives:

For any project, there are goals that must be achieved for the project to be successful. Goals can range from first cost, to time schedule, to number of change orders, or to life-cycle cost. Regardless of which goals are identified, they must be summarized up front to ensure everyone is on the same page. The objectives for accomplishing this project are detailed in this section.

Functional Uses:

The expected functional uses (spaces) for the facility are detailed in this section. A short description of each functional use is included to provide the context in which it was detailed.

Occupancy Requirements:

Includes the number of occupants (users and visitors) and the schedule of occupancy, including all special conditions.

Budget Considerations and Limitations:

The expected budgetary restrictions and considerations are contained in this section.

Performance Criteria:

The performance criteria upon which the project will be evaluated by the Commissioning Team are included in this section. Each performance criterion should be measurable and verifiable. This section includes subsections, as appropriate, to organize and explain the criteria: General;

- Economic;
- User Requirements; Construction Process;
- Operations; and
- Systems Assemblies

Owner's Project Requirements Version History:

Includes a summary of the changes made throughout the Pre- Design, Design, Construction, and Occupancy and Operations Phases. This information is critical to understand and document the trade-offs made over time and the resulting impact on the project.

Table F-1 will assist in the development of the Owner's Project Requirements document in accordance with Section 5.2.2.4 using the format presented in this appendix. The table is also applicable for those developing Technical Supporting Guidelines as described in Appendix A. Inclusion of specific criteria (such as the entries in this example matrix) will depend upon the project and the Owner's needs. The Key Owner's Project Requirements Section should emphasize those OPR that are essential to the success of the project (ASHRAE, Guideline 0-2005).

Table F.1 Example Matrix for Developing Owner's Project Requirements

	Guideline 0-2005 Sub-clause 5.2.2.4 Criteria	OPR Document Section						
		Introduction	Key Owner's Requirements	General Project Description	Objectives	Functional Uses	Occupancy Requirements	Budget Considerations and Limitations
		1	2	3	4	5	6	7
(a)	Project Schedule and Budget			Schedule				Budget
(b)	Commissioning Process scope and Budget	Scope						Budget
(c)	*Project Documentation requirements, including format for submittals, training, materials, reports, and the System Manual. Consideration should be given to use of electronic format documents and records where appropriate.*		X					
(d)	*Owner Directives*		X					
(e)	*Restrictions and Limitations*			X				
(f)	*User Requirements*		X					
(g)	Occupancy requirements and schedules					X	X	
(h)	Training requirements for Owner's personnel.		X					
(i)	Warranty requirements		X					
(j)	Benchmarking requirements.		X					
(k)	Operation and maintenance criteria for the facility that reflect the Owner's expectations and capabilities and the realities of the facility type.		X					
(l)	Equipment and system		X	X				

Table F.1 continued

	Guideline 0-2005 Sub-clause 5.2.2.4 Criteria	OPR Document Section						
		Introduction	Key Owner's Requirements	General Project Description	Objectives	Functional Uses	Occupancy Requirements	Budget Considerations and Limitations
		1	2	3	4	5	6	7
	maintainability expectations, including limitations of operating and maintenance personnel.							
(m)	*Quality requirements for material and construction*		X					
(n)	*Allowable tolerance in facility system operations.*			X				
(o)	*Energy efficient goals.*		X	X				
(p)	*Environmental and sustainability goals.*		X	X				
(q)	*Community requirements.*		X					
(r)	*Adaptability for future facility changes and expansion.*		X	X		X		
(s)	*Systems integration requirements, especially across disciplines.*					X		
(t)	Health, hygiene, and indoor environment requirements.		X				X	
(u)	*Acoustical requirements.*		X					
(v)	*Vibration requirements.*		X					
(w)	*Seismic requirements.*		X					
(x)	*Accessibility requirements.*		X					
(y)	Security requirements.		X					
(z)	Aesthetics requirements		X					
(aa)	Constructability requirements.		X					
(bb)	*Communication requirements.*		X					
(cc)	*Applicable codes and standards.*			X				

Table F.1 continued

	Guideline 0-2005 Sub-clause 5.2.2.4 Criteria	OPR Document Section							OPR Version History
		General	Economic	User requirement	Construction process	Operation	System	Assemblies	
		8	9	10	11	12	13	14	15
(a)	Project Schedule and Budget								
(b)	Commissioning Process scope and Budget								
(c)	Project Documentation requirements, including format for submittals, training, materials, reports, and the System Manual. Consideration should be given to use of electronic format documents and records where appropriate.								
(d)	Owner Directives								
(e)	Restrictions and Limitations								
(f)	User Requirements			X					
(g)	Occupancy requirements and schedules								
(h)	Training requirements for Owner's personnel.				X	X			
(i)	Warranty requirements					X			
(j)	Benchmarking requirements.		X		X	X	X		
(k)	Operation and maintenance criteria for the facility that reflect the Owner's expectations and capabilities and the realities of the facility type.					X	X	X	
(l)	Equipment and system maintainability expectations, including limitations of operating				X	X	X		

Table F.1 continued

	Guideline 0-2005 Sub-clause 5.2.2.4 Criteria	OPR Document Section							OPR Version History
		General	Economic	User requirement	Construction process	Operation	System	Assemblies	
		8	9	10	11	12	13	14	15
	and maintenance personnel.								
(m)	Quality requirements for material and construction	X			X		X	X	
(n)	Allowable tolerance in facility system operations.					X	X		
(o)	Energy efficient goals.	X	X			X	X	X	
(p)	Environmental and sustainability goals.	X							
(q)	Community requirements.								
(r)	Adaptability for future facility changes and expansion.	X			X	X	X	X	
(s)	Systems integration requirements, especially across disciplines.				X				
(t)	Health, hygiene, and indoor environment requirements.	X		X					
(u)	Acoustical requirements.	X		X	X				
(v)	Vibration requirements.	X			X				
(w)	Seismic requirements.	X			X				
(x)	Accessibility requirements.	X		X	X	X			
(y)	Security requirements.	X		X	X				
(z)	Aesthetics requirements	X		X	X				
(aa)	Constructability requirements.	X			X				
(bb)	Communication requirements.	X		X	X				
(cc)	Applicable codes and standards.								

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